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Capture-and-Containment Systems for Hazardous Material Spills on Land

MSA Research Corp., Evans City, PA

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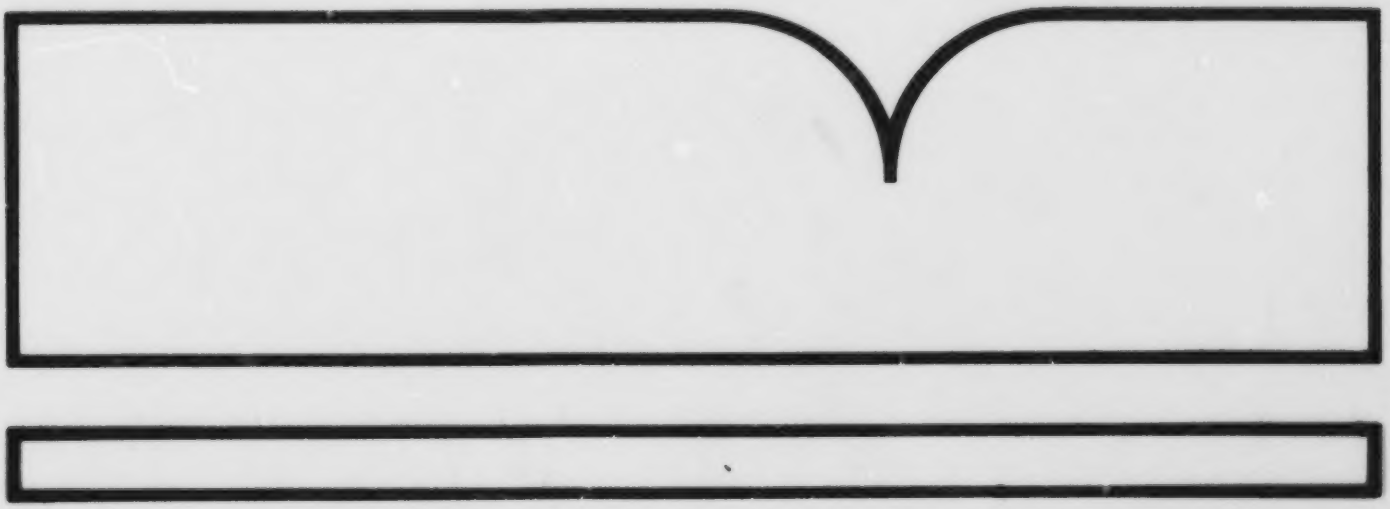

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CAPTURE-AND-CONTAINMENT SYSTEMS FOR HAZARDOUS MATERIAL SPILLS ON LAND

by

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Contract No. 68-03-2507

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16. ABSTRACT

This report covers the investigation of methods for sealing the surface of soils and preventing the percolation of spilled hazardous materials into the ground. The objective was to develop a portable, self-contained, universal sealing system which could be operated by one man, retain the spilled material through a 24-hr removal period, and pose no subsequent hazard to the user or to the environment.

Sprayable sealant systems were investigated extensively but proved to be impractical. Of the sealants investigated, only polyurethane foam showed any promise of sealing soil surfaces particularly under the severe weather conditions that generally accompany bulk transport accidents. However, the quantity of chemical required to seal soil (especially grassy substrates) far exceeded the amount considered practical for a portable system.

Polyethylene film in the shape of a one-end-closed tube proved to be the most practical means of containing and collecting hazardous material spills. An apron attached to the open end was equipped with draw and tie ropes to position the device under or close to the spill. A small tube connected at the closed end allowed for transferring collected spilled material to auxiliary containers. A double-walled bag consisting of a heat-sealed inner bag and a reinforced outer bag appeared to be the combination most suitable for further development. Total collapsed volume of the final package, a pillow-shaped containment bag 20 ft long and 6 ft wide, was less than 2 ft^3; the unit weighed less than 16 lb.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report discusses novel methods to prevent the percolation of spilled hazardous materials into the ground. Sprayable sealants proved to be impractical under the diversity of spill conditions expected. Manufactured films such as polyethylene, on the other hand, appear to be practical and were developed further into a promising, first-action capture-and-containment bag.

Francis T. Mayo,
Director
Municipal Environmental Research
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ABSTRACT

This report investigates methods for sealing the surface of soils and preventing the intrusion of hazardous materials into ground water. The objective was to develop a portable, self-contained, universal sealing system that could be operated by one man, retain the spilled material through a 24-hour removal period, and pose no subsequent hazard to the user or to the environment. A basic assumption of this investigation was that the site preparation for any sealing system would be minimal.

Sprayable sealant systems were investigated extensively but proved to be impractical. Three types of sealants were investigated: nonreactive, (which are dispersed or dissolved in a solvent system), reactive (which are two or more component systems) and repellent or surface modifiers. Only polyurethane foam, a reactive type, showed any promise of sealing soil surfaces under the variety and severity of weather conditions that are often the cause of bulk transport accidents. But even with this promise, the quantity of chemical required to seal soil (and especially grassy substrates) sufficiently to contain the spilled material far exceeded the amount considered practical for a portable system. In addition, the techniques for applying the sealant to different soil substrates under various weather conditions were a big factor in effecting a seal and thus made it too complex for a simple, first-response action.

Polyethylene film proved to be a practical barrier to a wide spectrum of hazardous agents and sealed against water at over a foot of head when applied to rocky, grassy, and weedy areas. When formed in the shape of a tube approximately 6 ft in diameter and approximately 20 ft long, the unit would contain water with more than 3 ft of head and have a capacity of more than 1000 gal. An apron on the open end equipped with draw and tie ropes allowed positioning of the unit below the leak, and a small tube connected at the closed end allowed for directing excess spill to a second containment site. The enclosed bag concept would also minimize vapor hazards.

A double-walled bag consisting of a heat-sealed inner bag of clear polyethylene and a sewn, reinforced outer bag appeared to be the combination most suitable for further development. The final package had a volume of less than 2 ft^3 and weighed less than 16 lb.

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SECTION 1

INTRODUCTION

Concern about the control of chemical spills has increased in both the public sector and the scientific community. The incidence of accidental land spills has increased proportionally to the growing use and transport of chemicals. This concern is at least partly the result of several incidents in which ground water has been contaminated by percolation of the spilled material.

Most of the scientific activity in this area has been directed to monitoring the fate of the spilled material or health effects resulting from its presence. Relatively little has been done to develop methods to alleviate the problem of contaminated ground water. Present action involves either the physical removal of the soil from the spill-affected area and disposing of it at a secured landfill, or the drilling of "cone of influence" wells to drain off the polluted water for conventional treatment. These techniques are slow and expensive.

This report contains the results of an investigation of methods to seal the surface of soils and prevent the intrusion of hazardous materials into the ground. The objective was to develop a portable, self-contained, universal sealing system that could be operated by one man, retain the spilled material throughout a 24-hr removal period, and pose no subsequent hazard to the user or to the environment.

The hypothetical scenario for the use of a soil sealing system assumed that it would be employed immediately after a spill, possibly in conjunction with diking materials, to confine the material to the immediate vicinity of the accident. The response procedure would utilize the transportation personnel or local safety personnel who were first on the scene to determine the probable course of flow, to locate a containment site, and to initiate capture-and-containment procedures.

One basic assumption of this investigation has been that site preparation for any containment or sealing system would be minimal. Conceivably, some intermediate-sized debris could be moved, but the ideal sealing system would be capable of surmounting most obstacles. Since accidents frequently occur during inclement weather, wet or frozen substrates have been considered common conditions for operation. The design goals for the system were as follows. The system must be:

1. Portable and capable of operation by one man (maximum weight 40 lb).
2. Self-contained.
3. Operable in a safe manner.
4. Operable in a manner such that no permanent secondary environmental damage results.
5. Capable of fabrication from commercially available components to the maximum extent possible.
6. Capable of reducing soil penetration by 95% on a land area 1200 ft^2 under 1 ft of liquid head for a 24-hr period.
7. Capable of sealing many types of soils under varied terrain conditions with minimum site preparation.
8. Capable of application in varied weather conditions.
9. Capable of sealing when applied before or after spill front has passed an area; i.e., "dry" or "wet" areas.
10. Capable of preventing the spilled material from seeping under the edge of the sealed area.
11. Capable of being removed after the spill incident is terminated.

The program was designed (1) to select and evaluate film-producing sealing materials that could be used to form a leak-free barrier on solids in hazardous spill situations, and (2) to design and fabricate a prototype device to dispense the materials and demonstrate its usefulness for production. The project completed only two of four scheduled phases when it became apparent that design goals could not realistically be achieved. No sealant candidate was found that could be applied to essentially unprepared terrain with any reasonable assurance of an effective seal even under ideal conditions. Polyurethane foam was considered the best of the candidates surveyed. But when it was applied to grassy areas, it could not form a dependable seal even at rates approaching 0.13 lb/ft^2--far in excess of the 0.02 lb/ft^2 rate of the design goals, and impractical on the basis of costs and logistics.

Manufactured films that could be used as a barrier were not specifically excluded by the design criteria, but they were not to be considered in the primary program effort. When a suitable film-producing sealant could not be found, however, our efforts were directed towards other methods that might achieve the program goals in a practical manner.

Of the various commercial film materials available, polyethylene (PE) was the most economical and had the widest range of compatibility with the representative list of hazardous materials. Moreover, it has widespread commercial applications and is a common item of commerce. The potential was therefore extremely good for developing a spill-control package inexpensive enough for widespread distribution to the common carriers or local emergency response teams, or for ready local availability to a spill site.

Polyethylene film was first investigated as a replacement for the sealant in the initial spill scenario, considering its suitability for

various terrain conditions, methods for deployment under adverse weather conditions, and formation of suitable holding ponds from sheet material. The concept proved to be practical.

The capture-and-containment-bag concept evolved from the idea of a polyethylene-film holding pond. A means was needed to capture the spilled liquid and direct it to the temporary holding ponds, which may be some distance from the spill.

The original idea was to use a 1.5- to 3-ft-diameter plastic-film tube with a capture apron on one end that could be pulled under and around the spill, and to run the captured material down the tube to the containment pond. The containment-bag concept grew from a need to hold some of the spilled liquid temporarily until the ponds could be assembled. To accomplish this, the tube was enlarged for increased holding volume, forming a bag, and a small tube attached to the base of this bag for eventually transferring the captured liquid to the pond. The use of a larger bag for both capture and temporary storage was a logical outgrowth.

The work presented in the body of this report deals with the development of the capture-and-containment-bag concept, detailing its development, testing, and recommendations for further development. In our opinion, it is a simple and practical first-response solution for controlling a large percentage of spills from bulk transport accidents.

The initial program effort pertaining to sprayable sealants developed a significant body of data that were negative to the program objective but are worthwhile reference information. These data are presented in the Appendix.

SECTION 2

CONCLUSIONS

The search for a soil-sealing system to be used immediately after an accidental transport spill showed that polyethylene film has the most promise of being a basic barrier material. Containment ponds formed from PE sheet material and bags capable of holding 1000 gal were demonstrated successfully under adverse soil conditions. Polyethylene is readily available, chemically resistant, and inexpensive. Moreover, its physical properties are amenable to the inclement weather conditions prevalent in most transport spills.

Bags formed from 6-mil polyethylene film can hold more than a 1-meter head of water without rupturing. Reinforced polyethylene is available with even greater rupture and tear strength.

Heat-sealed seams on the units were the weak points. Sewn seams, though prone to seep under pressure, proved to be more dependable. Double-lined units with a heat-sealed inner bag and a sewn seam outer bag appear to be the most leak-free, puncture-proof, and strongest design for containing spills under higher head conditions.

A prototype design consisted of a 20-ft-long, 6-ft-wide bag with a 10-ft-long apron that collects the spill liquid and directs it into the bag. Tie lines on the apron are used to position the device on the ruptured tanker.

A transfer tube attached to the bottom of the bag allows liquid transfer to a secondary container. This design allows a modular approach to containing spill liquid in several tandem devices.

These bags can hold more than 1000 gal on reasonably sloping terrain. They weigh less than 16 lb each, occupy less than 2 ft^3, and could be produced in quantity for $50 to $200 each, depending on the complexity.

Field demonstration tests of two capture-and-containment devices confirmed the modular approach. More than 1000 gal of liquid were collected over 5 hr and stored without loss.

Polyethylene film is also a suitable barrier for fabricating emergency holding ponds. Polyethylene film 6 mils thick contained water with more than a foot of head when installed over weeds, rock, and other debris. Large sheets would be difficult to deploy under wind conditions,

but mechanical fasteners are available to join smaller sheets and thus form barriers for larger pond areas.

Use of film-producing chemicals for onsite sealing of soils was not practical. Applying the film-forming formulations to substrates likely to be found on berms and ditches near highways and railways produced barriers that leaked through holes or seepage.

Three film-producing classes were investigated:

Nonreactive sealants are those that have been previously polymerized and are either dispersed or dissolved in water or other solvents. These depend on solvent evaporation for film formation. Thus they are slow to form at low temperatures. If such nonreactive sealants are in organic solvents, the vapors may pose a fire hazard. The films formed under ideal soil conditions often had pinholes. Leak-free films were not possible over rough terrain and vegetation.

Reactive sealants are composed of two or more component systems that react on application to form a polymer. They are more likely to form films under adverse weather conditions than are the nonreactive sealants, but they have several problems. Applications to snow-, ice-, or water-covered surfaces cause frequent holes in the film and result in poor adhesion to the substrate. Applications to vegetated areas often do not reach the soil, but form poorly-bridged films with frequent holes, especially adjacent to the vegetation. Pinhole-size voids are commonplace in the films formed even on well-prepared substrates.

Surfactant chemicals consist of repellent chemicals that modify the surface characteristics of materials so that they are not wetted. These failed to seal against candidate spill liquids when applied to soils under ideal conditions. Two of the more promising surfactants investigated (E. I. duPont de Nemours' fluorocarbon Zonyl RP and Clintwood Chemical Company's surfactant Clindrol 100 CG did not retain the candidate spill liquids when applied to well-prepared soils at 22 to 25°C. Even less success would be expected on snow, ice, rain-soaked soil, or vegetation.

SECTION 3

RECOMMENDATIONS

The capture-and-containment-bag concept as a first-response measure for the control of hazardous spill materials from bulk tankers should be vigorously pursued. The units are potentially inexpensive, and their use in spill situations is readily obvious to spill response personnel. They are therefore attractive candidates for onboard emergency spill-containment units for trucks and rail tankers or for distribution and use by local emergency response teams.

The basic film strengths of fiber-reinforced PE films are more than adequate for the intended use, but seams need additional study. Sewn seams are strong, but they seep. Heat-sealed seams are leak-free, but sometimes they fail even at low head pressures. For these reasons, a double-walled bag with a heat-sealed inner bag of clear, low-density PE combined with a sewn-seam outer bag of fiber-reinforced PE offers the best promise of a reliable final design.

Before potential bag manufacturers will direct serious efforts to solving the several design problems evidence is needed of a potential market. The design of the units should be evaluated in line with present-day bag manufacturing techniques. Quality control was less than adequate on seams and dimensions of the handmade test units provided by bag suppliers.

An expanded program should include:

(1) Improvements in design as a result of discussions with potential bag manufacturers and spill-response personnel. Discussions with experienced spill-response personnel should consider the need for a lined bag, overall size, capture apron configuration, placement of grommets for deployment and stabilization, etc. This information can then be considered in design discussions with commercial film and bag fabricators.
(2) Evaluation of commercially manufactured bags to test the capability and reliability of machine-formed heat-sealed seams.
(3) Field evaluation of limited production samples by EPA and local spill-response personnel.

Experienced spill-control personnel have recommended further evaluation and testing of the concept. Personnel from the Pennsylvania Department of Environmental Resources in charge of spill control in the Pittsburgh district observed a test of the fabricated bag. They were impressed with the simplicity of the concept, enough so to recommend in writing its further development and to request units for testing on actual spills.

SECTION 4

MODULAR CAPTURE-AND-CONTAINMENT-BAG CONCEPT

CONCEPT DEVELOPMENT

The capture-and-containment-bag concept evolved from a need to capture spilled liquid and direct it to temporary holding ponds constructed of polyethylene film possibly some distance from the spill. The original idea was to use a narrow plastic-film tube with a capture apron on one end that could be pulled under and around the spill source, and direct the captured material down the tube to the containment pond. The bag concept grew from a need to hold some of the spilled liquid temporarily until the containment ponds could be assembled. To accomplish this, the tube was enlarged to increase holding volume, forming a bag, and a narrow tube was attached to the base of this bag to direct the captured liquid to the containment pond. The tube would be tied off until the pond was ready.

With the success of the initial bag concept, the idea of having additional bags to hold captured spill, rather than construct polyethylene-lined holding ponds, was even more attractive. The use of bags rather than the open ponds gave better vapor control. In addition, bags were easier to deploy than plastic sheeting and needed no film joining, hardware, or diking materials to help contain the liquid. The assumptions used as a design basis for the final device were as follows:

- The total available spill material may be as much as 10,000 gal; however, in better than 95% of the cases, the spill rate will be such that the total spill will be less than 1000 gal.
- Containment for at least 1000 gal will be made available in the capture-and-containment-bag for quick, easy deployment by one man. Subsequent containment units will be developed in 600- to 1000-gal modules.
- For safety, the connection to the spill source will be made only once. The capture system will thus act as an emergency containment system, but have the added capability of directing any overflow, if this is required, to subsequent containment devices downstream.
- Diking material will not be available for the deployment of the initial first-action capture-and-containment system. It might, however, be available for the development of subsequent downstream

containment areas, which could take the form of additional bags or plastic-film-lined ponds.

- Procedures and/or a handbook describing techniques for connecting simple spill containment modules, or the use of polyethylene sheeting and sealant/fasteners to form holding ponds will be developed for in-field use by spill containment personnel.

The final concept -- the basics of which are shown in Figures 1 and 2 -- consists of a polyethylene-lined, pillow-shaped bag, about 6 ft wide and 20 ft long, with an apron on one end. The apron has rope lines attached to each corner which allow it to be pulled through an existing spill on the ground, directing the liquid into the attached pillow bag. Subsequently, these lines would be used to pull the apron into position under the ruptured tanker and tied to the tanker in a slightly elevated fashion so as to direct the hazardous liquid leaking from the tanker into the bag. Lines located around the opening into the bag could be used for additional support.

The overflow is a 4-in -diameter polyethylene tube, approximately 30 ft long. It can be tied off near the bag, or laid out upstream along the bag to prevent loss of liquid. The tube can be used for emptying the bag for cleanup, or for directing overflow to additional storage downstream.

PROTOTYPE TESTING

Most of the problems with the prototypes involved the heat seals, especially at the high stress points where the transfer tube was connected. Some of this probably was due to the priorities placed on the fabrication of these bags by the suppliers. Since it was a developmental program, with no immediate large commercial possibilities, the units were all hand fabricated -- and usually only with a considerable delay in delivery.

Seal strength of Commercial PE Film Bags

The plastics fabricating firms expressed reservations concerning the reliability of polyethylene films to retain liquids under a 1-ft pressure head. These opinions, given by people with considerable experience, did not coincide with the data obtained in our preliminary bag testing, which indicated that both the films and the heat seals would have sufficient strength for the proposed use. The discrepancies with laboratory data and concern for system safety dictated a series of tests to determine the strength of the films recommended for this capture-and-containment device and a safe pressure range for fail safe heat seals.

A series of tests under controlled air pressures measured the strength and integrity of commercially-available 4-mil-thick bags. The bags were attached to the test apparatus in Figure 3 and subjected to pressures of 15 and 30 in. W.G. over a period of time. Tests in which the bag showed no stress after some period at around 30 in. W.G. were continued at higher pressures.

Figure 1. Capture-and-containment device, showing dual-layer polyethylene film construction and collecting apron.

Figure 2. Deployment of device as used in simulated field test.

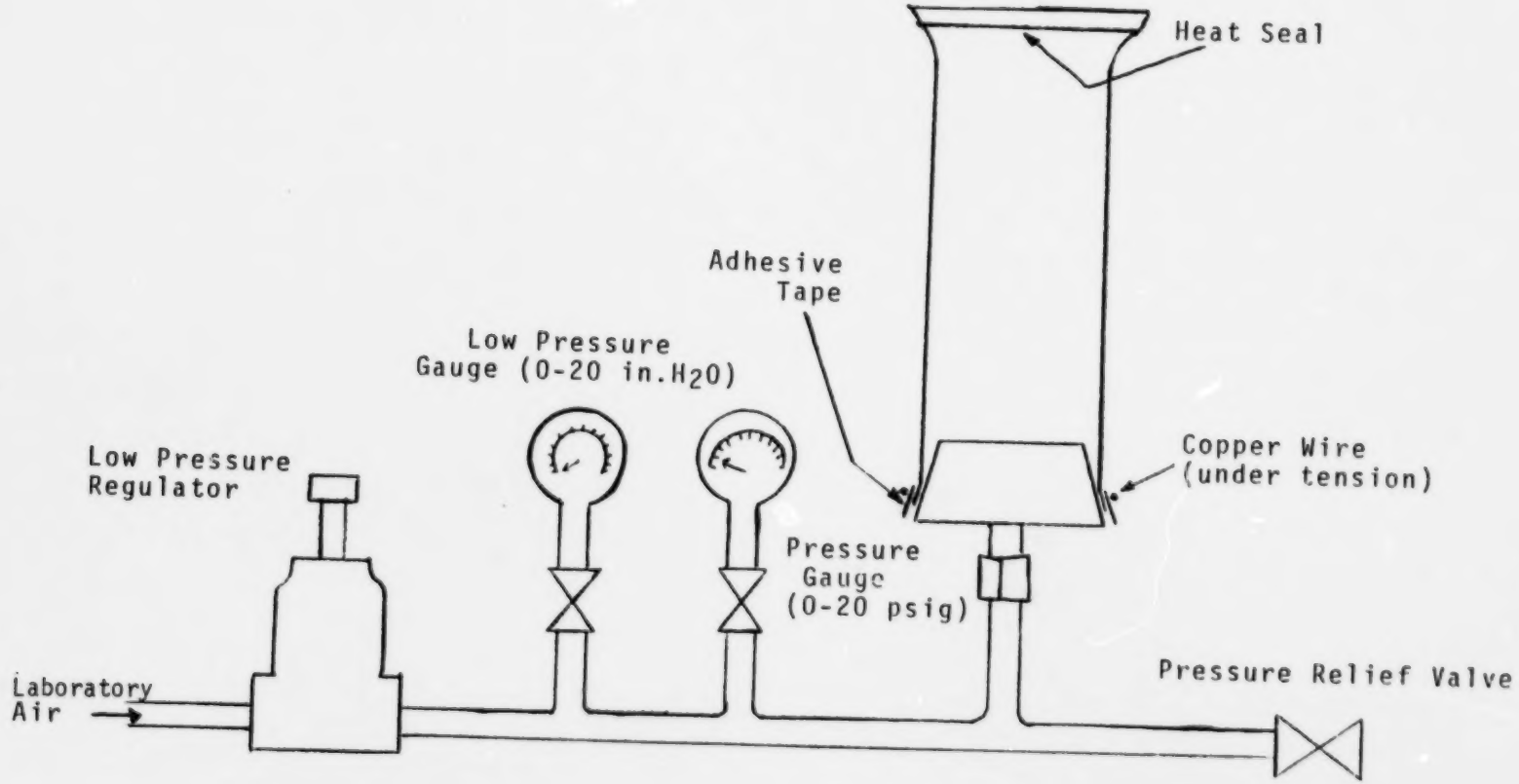

Figure 3. Apparatus used to determine the strength and integrity of polyethylene bags

The results and comments are summarized in Table 1.

The results indicated that polyethylene bags are indeed strong enough for the proposed use, but that the following generalizations should be considered in the fabrication of any capture-and-containment device:

1. Quality control procedures generally used for mass production units would be insufficient for the proposed plastic film fabrication.
2. Heat seals are as strong as the base material when properly made.
3. Improperly made heat seals, which may pass present quality control checks, may have defects which would not hold any liquid.
4. Plastic deformation of 4 mil (0.004 in.) thick film occurs during the first 3 hr of exposure to pressure heads of approximately 30 in. H_2O.
5. Failure of these same films required between 75 and 80 in. H_2O for rapid failure.

Testing of Laboratory-Fabricated Clear PE Bags

Two prototype pillow bags were fabricated from 4 mil (0.004 in.) polyethylene plastic tubing. Standard 6-ft wide (laid flat) tubing was cut from a stock roll and one end heat-sealed shut with a hand-held clamshell-type heat sealer. The other open end was cut, removing half of the tube for about 2 ft to provide an apron.

In the first test, the bag was deployed as a rolled-up tube, 4 in. in diameter, at the spill site. Water, the simulated hazardous liquid, was fed from a hose at approximately 1.5 gpm to the bag. As the water head built up in the end of the bag, the bag unrolled down a hillside with about a 10% grade (1 ft/10 ft). Full deployment occurred in less than a minute. Water was allowed to flow into the bag for 3 hr. 45 min. (340 gal) building a maximum head of 13 in. with an estimated average head of 8 in. No change occurred over 24 hr.

In the second test, a similar bag, but with a 5-ft-long apron, was used. The bag was deployed at a 45 degree angle to the downhill slope of the terrain. This position was chosen to determine the tendency for the pillow-shaped bag to roll as it filled if not placed exactly downhill on a sloping terrain.

Again, the bag was placed as a roll, with the apron deployed and attached as if collecting liquid from under a ruptured tanker. The mouth of the bag was held open by separating the film with several small rocks and water was supplied onto the raised apron at the rate of 5 gpm. At the 5 gpm feed rate, water first overflowed the bag without unrolling it, but with a slight push it quickly unrolled with only a 2 in. head. In 5 min, with 25 gal of water, the bag rolled sideways slightly. After 22 min and 110 gal of water, further movement sideways allowed water to overflow the top rather than run to the bottom of the bag. The tie-downs on the

TABLE 1. RESULTS OF STRENGTH TESTS WITH COMMERCIAL POLYETHYLENE BAGS (6 in. x 9 in., nominal 0.004 in. thick)

Sample	Pressure (in. H_2O)	Exposure Time (hr)	Mode of Failure
1	15	1	Did not fail, some deformation.
	30	3	Did not fail, no further deformation.
2	30	0.5	Did not fail, some deformation.
	110	<0.0001	Failed through heat seal.
3	35	1	Did not fail, some deformation.
	75	0.003	Failed through sidewall.
4	30	<0.01	Poor heat seal.
5	30	0.5	Did not fail, slight deformation.
	80	0.005	Failed through sidewall.
6	30	>0.01	Partial separation in heat seal.
	80	0.0001	Failed through sidewall.
7	30	2.5	Partial separation in heat seal from deformation.
8	30	3	Failed through heat seal.
9	30	30	Did not fail; laboratory heat seal.
	85	> 0.01	Failed through sidewall.

apron held the bag in place at that point. Cutting the tie-downs from the projected ruptured tanker allowed the bag to roll down the hill sideways and empty in the process.

A third test used the same bag, but with the bag deployed straight down the 10% grade slope. The apron was held 16 in. above ground level as if tied on the opposite side of the tank rupture, and water was added at the same rate (5 gpm) to the apron. It was again necessary to prop open the bag mouth with a large rock so that the water readily flowed between the plastic film layers.

In the first test, 315 gal of water were contained at a maximum head of 14.5 in. over a 20-hr period. A total of 600 gal of water with a maximum head of 24 in. was collected in the bag before failure occurred along a fold line in the polyethylene tube. The leak was approximately 6 ft from the sealed end of the bag at a point with about 20 in. of head. Fold lines of polyethylene sheeting are notoriously weak points.

Testing of Fiber-Reinforced PE Bags

Bags fabricated from fiber-reinforced plastic films were evaluated to obtain increased strength and puncture resistance. Reinforced films are made up of a woven plastic, mat-like reinforcement fabric coated on both sides with a thin film. This construction gives the material high tear, puncture, and abrasion resistance, the degree of which are a function of the density of the fiber weave.

The first unit was made of a film fabricated with 0.125 in. vinyl fibers on a 0.25 in. weave. The bag was 8 ft wide (laid flat) with a 10 ft apron, a 20 ft bag section and a 30-ft-long overflow tube. This unit, fabricated by A. Mamaux and Son, Pittsburgh, PA, was the first with a transfer tube to direct any overflow to subsequent containment devices or systems downstream.

The bag was double-stitch sewn, with the stitching covered with polyethylene mastic tape to prevent leakage. It weighed approximately 16 lb and was relatively easy for one man to deploy.

In the first test, the bag was deployed as a rolled-up tube at the 10% grade test site. The bag was unrolled by the single operator in freezing temperatures in 6 in. of snow, and the transfer tube was deployed back up the slope alongside the bag. Water flowed into the bag at 5 gpm. At a total of 450 gal and a maximum head of 9 in., a leak developed in the device at the sharp inside corner of the bag where the transfer tube was attached. The leak was in the film fabric and not in the sewn seam, but failure was thought to be caused by the stresses resulting from the sharp angle at the attachment point.

Moving the transfer tube to empty the contained liquid from the bag was successfully carried out, but with difficulty. The transfer tube's flat width of nearly a foot was obviously too large, making it heavy when filled with liquid.

The leak in the A. Mamaux unit was repaired, and the size of the transfer tube was reduced to 9 in. (laid flat). A radius was also included at the point of attachment to reduce stress at this point.

The bag was again deployed on the same downhill slope and supplied with water at a rate of 5 gpm onto the raised apron. Water height measurements were taken every hour, as well as color photographs of the progress. After 3 hr, 900 gal of water filled the bag to a length of 14 ft and 22 in. deep at maximum head. No appreciable leaks were observed; however, some seepage was observed at the sewn seams.

A second test with the same bag was conducted to determine the maximum head the bag would hold on the 10% slope. The apron was tied above ground level as if tied on the opposite side of a tank rupture, and water was added at the same rate (5 gpm). A total of 1350 gal was collected in the bag in 4.5 hr before a seam began to leak (Figure 4). The leak again was at the point of attachment of the transfer tube to the bag (Figure 5). Water filled the bag to a 17-ft length with a maximum head of 26 in.

The water was removed from the bag via the transfer tube. The transfer time was about 9.5 min, at a rate of about 142 gpm.

Although not completely successful, these tests indicated the feasibility of the capture-and-containment-bag concept. Deployment was easy, and the containment safe to a reasonable head of liquid. It was obvious, however, that more careful attention was needed at seams and attachment points.

Testing of Fiber-Reinforced Bags from Commercial Fabricators

Commercially-fabricated capture-and-containment-bags of fiber-reinforced PE, similar to the ones tested, were solicited from several commercial bag manufacturers with the hope that their expertise in this field could aid in solving our seam problem. Their comments were solicited on the overall design, including the shape, type of fabrication, and seal at the transfer tube.

Only three companies agreed to fabricate test bags, none enthusiastically. These bags were received over a period of nearly a year and were tested very similarly to the test previously described. Water, as the test liquid, at a rate of 5 gpm, was added to the bags secured on a sloping terrain of about 10%. Periodic measurements were taken of the maximum height of water contained versus the volume of water added, and the mode of failure, if any, was evaluated. Modifications were then agreed to in conjunction with the supplier, and the bag was retested. A summary of these tests is shown in Table 2.

Griffolyn Company supplied four bags made of Griff-Weave 24, a film with 0.125 in. high-density PE fibers on a 0.125 in. weave sandwiched between 2-mil clear low-density PE film. The total thickness was 8 to 9 mil. The material is exceptionally tough. A tear strength of 750 lb/ft^2

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Figure 4. Capture-and-containment device with sewn seams being tested to maximum containment pressure head.

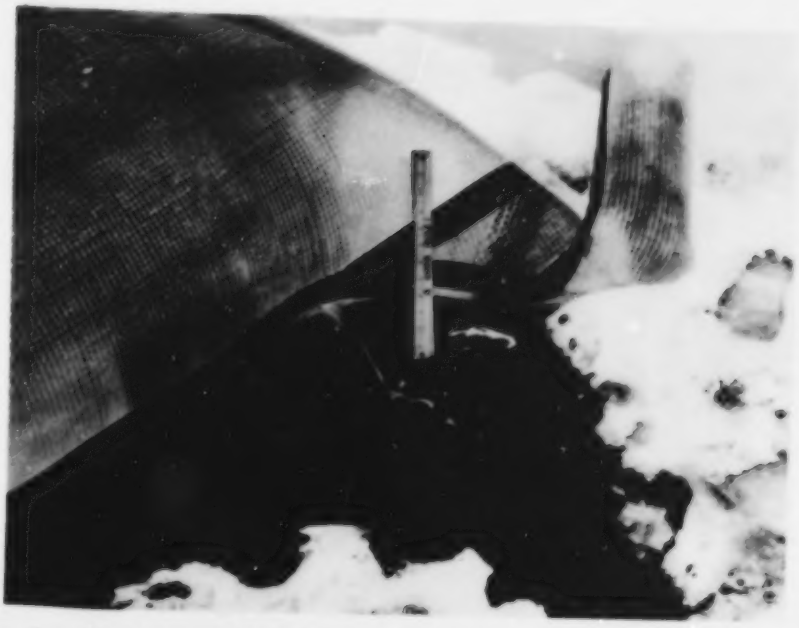

Figure 5. Rupture of the device in the transfer tube attachment area.

TABLE 2. SUMMARY OF TESTS ON FIBER-REINFORCED BAGS FROM COMMERCIAL BAG MANUFACTURERS

Supplier	Type of Fabrication	Maximum Test Water Head (in.)	Comments	Weight (lb)
1. Griffolyn Company Houston, TX	Seams manually double-bar sealed	12	Failed near the seam - heat distortion	13.5
2. "	Double stitched sewn seams - silicone coated	12	Small leaks at jointed corners	--
3. "	Double stitched sewn seams - PE-tape coated	29.5	Filled to capacity (~1500 gal) Seams leaked at about 0.4 gpm	--
4. "	Hot-air blown heat-sealed seam	<5	Seams failed zipper-like	12.6
5. Silco Industries Newark, NJ	Heat-sealed seams	<5	Seams failed zipper-like	9.8
6. Katz Bag Company Indianapolis, IN	Proprietary extrusion process	48	Bag on 1/4-scale No failure	--
7. " (full scale bag)	Mechanical seal around transfer tube	12	Leakage around mechanical seal	--
8. "	Improved O-ring seal around transfer tube	--	Held for demonstration testing	--

was reported for the film by the supplier. In our own test, a slit that was cut in a sample of the film could not be propagated with bare hands; nor could a six-penny nail readily puncture it with only hand pressure.

The manually heat-sealed test bag (No. 1 - Table 2) failed quickly at about a foot of head, apparently as a result of heat-weakened film adjacent to the seam. Bags with sewn seams fared better. One coated with silicone (No. 2 - Table 2) leaked readily at the joints. The one with the PE-tape-covered seams (No. 3 - Table 2), on the other hand, did not fail catastrophically but seeped slowly at all seams. Unfortunately, a number of excess seams appeared to be present in the construction. This bag was, however, filled to capacity at about 1500 gal with a maximum head of about 29.5 in. (Figure 6).

A hot-air blown heat-sealed bag (No. 4 - Table 2) was apparently not well-sealed and opened up along the seams like a zipper early in the test. The seal at the seam was apparently not hot enough to involve the high density PE fibers, and the film just pulled apart. A bag submitted by Silco Industries (No. 5 - Table 2) with similar materials and fabrication techniques also failed in the same manner.

Katz Bag Company of Indianapolis, IN, a major fabricator of polyethylene film bags, supplied a single-ply fiber-reinforced polyethylene film fabricated on approximately 1/4-scale using their proprietary extrusion process. The bag was fabricated of polyethylene sheeting consisting of two layers of polyethylene ($\sim$1 mil) on either side of a polyethylene fiber matt. The sheet had a nominal thickness of 8 mil. Other thicknesses are available.

The bag (No. 6 - Table 2) was first tested to 2 ft and then to 4 ft head. Small holes appeared in the seams but none developed into a catastrophic failure. The strength of the bag material was more than adequate for liquid containment. The material was abraided by stones and vegetation, and "pinholes" developed within the sheet itself during the tests. Neither the heat-sealed seams nor these abrasive cuts in the sheet opened further, however, when the pressure head was increased to 4 ft.

The full-scale unit (No. 7 - Table 2) supplied by Katz Bag Company used a mechanical seal to attach the transfer tube to the bag. This seal consisted of drawing the two pieces of polyethylene (bag and delivery tube) around a 1-ft length of 3-in. diameter pipe. PVC pipe was used for the prototype device, although polyethylene or polypropylene would be used in the final design for better chemical resistance. This device was tested using the standard screening spill procedure and held only a 12-in. head of water before some seepage occurred around the mechanical seal.

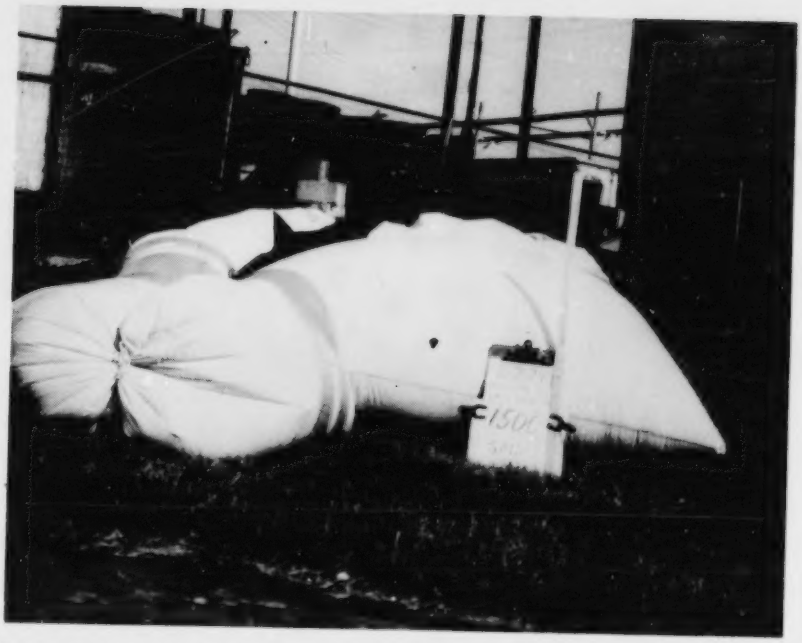

Figure 6. Capture-and-containment device fabricated of "Griff-Weave 24".

A third unit from Katz Bag Company (No. 8 - Table 2) incorporated an "O-ring" modification to their original mechanical seal at the transfer tube. This bag was tested successfully during the field demonstration using a railroad tank-car simulated spill.

Testing of Double-Walled Bags From Commercial Fabricators

Double-walled bag units with a seamless or heat-sealed clear polyethylene inner bag and a sewn reinforced-fiber outer bag construction were solicited from commercial manufacturers. The inner bag formed the leak-free liner -- the outer bag provided support for the higher pressures. Units from two companies were purchased. One from Sheldahl Corporation consisted of an inner bag of nominal 6-mil-thick polyethylene film and an outer bag constructed of "Poly-Tuff", a reinforced polyethylene film.

Testing was done on the sloping area used for all screening tests. Water was directed into the bag at 5 gpm with no signs of leakage until the pressure head was increased to 31.5 in. At that time the plastic in the area of the seal between the containment bag and the delivery tube appeared to be strained, and five small pinholes developed through the outer bag.

The flow of water was stopped after approximately 550 gal, and the device remained under the 31.5 in. head for approximately 45 min. During this time a slight bulging occurred along the side of the container bag. When the flow of water was resumed, the bag filled to a maximum head of 42 in. (Figure 7) when the leak rate equalled the addition rate. This leakage included a myriad of small droplets all over the surface of the outer bag, but the pinholes did not enlarge.

Post-test examination of the bag revealed that the seal of the inner bag in the section between the delivery tube and the containment bag was opened over a length of about 2 ft, typical of poorly heat-sealed seams in polyethylene. Although the inner bag had failed, the outer bag held well under the pressure.

The project was terminated before corrections and improvements could be made in the Sheldahl units. The prototype was of high quality and it is likely that shortcomings could be corrected, time permitting.

Silco Industries of Newark, NJ, fabricated a 1/4-scale, double-walled unit with a 4 mil PE inner liner with a continuous heat-sealed seam, and a PE mesh outer bag fabricated by a double-stitch-sewn-seam technique (Figure 8). The quarter-scale unit tested successfully to 46.5 in. of head with no leaks (Figure 9).

A full-scale double-walled unit submitted by Silco had a double-stitch-sewn outer bag of fiber-reinforced PE film. Although the outer bag was to have been fabricated slightly smaller than the inner bag to give immediate support on filling, such was not the case, and the outer bag provided only a loose fit. On filling, the inner bag seam failed

Figure 7. Capture-and-containment device fabricated by Sheldahl Corporation.

Figure 8. Construction details of a quarter-scale test device fabricated by Silco Industries.

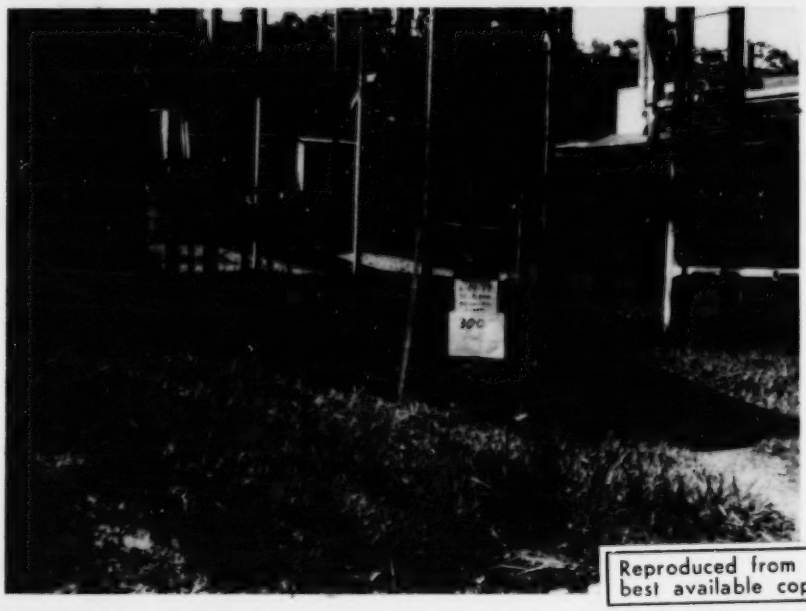

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Figure 9. Quarter-scale capture-and-containment device fabricated by Silco Industries.

near the transfer tube connection after only 150 gal.

Despite the above failure, a unit from Silco Industries with this same design, but with close fitting bags and more careful attention to inner bag construction, was tested successfully in our field demonstration.

Summary of Capture-and-Containment-Bag Concept Testing

Capture-and-containment-bags appear to be extremely attractive "first-action" devices for the control of emergency spills of liquids. Unit capable of containing about 1000 gal weigh less than 20 lb and occupy a storage volume of less than 2 ft^3, depending on the design. Manufacturing costs are estimated at less than $200, with some suppliers estimating cost in the $50 range. In addition, their deployment is not only simple, but obvious. They are therefore attractive candidates for onboard emergency spill-containment units for truck and rail tankers or for distribution and use by local emergency spill teams.

Field Demonstration

A field demonstration was conducted with two prototype capture-and-containment-bags at a site at MSA Research Corporation. The simulated accident was a railroad tanker laid on its side with leakage around the top hatch (Figure 10). Water was the simulated spill liquid at a leak rate of 5 gpm.

The spill site had only a gentle slope away from the tanker, which limited the allowable head buildup in the bags and thus total containment capacity. It did, however, demonstrate the ease of placement, the utility of the bags, and the ability to contain significant liquid under even these conditions by use of the modular bag concept.

The field demonstration tested two units selected as the most promising -- one fabricated by Silco Industries, Inc. and one from Katz Bag Company.

The Silco Industries' unit consisted of an inner bag fabricated from 6 mil clear polyethylene film by continuous heat sealing of all seams, and an outer bag fabricated from fiber-reinforced PE film with double-sewn seams. The outer bag material was a close weave 1/8 in. count x 1/8 in. wide polyethylene fiber-reinforced 9-mil-thick polyethylene film. Both bags had essentially the same dimensions so that the outer bag would retain the more elastic inner unit on filling.

Grommets for tie lines were installed at several positions along the opening to the bag (Figure 11) and around the apron to assist in deployment and capture of the liquid. The lower end of the bag, rather than being

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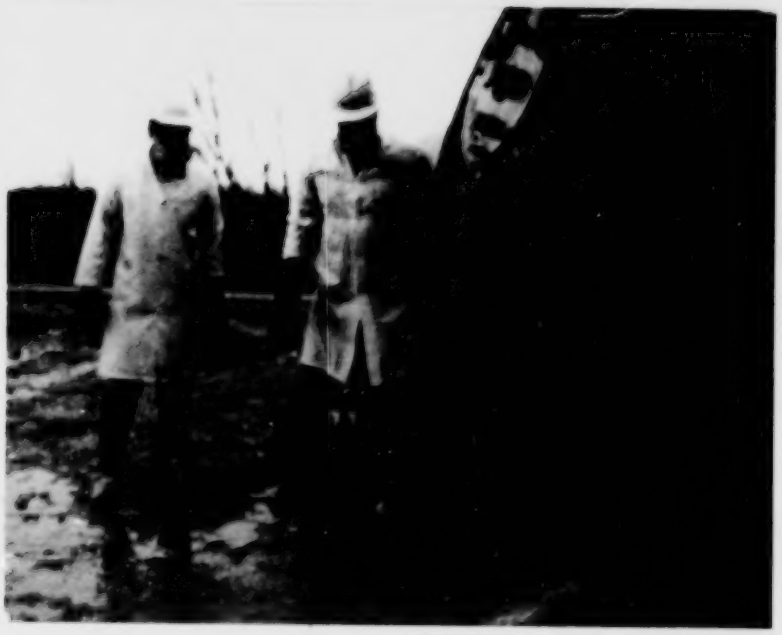

Figure 10. Simulated tanker accident for field test demonstration.

Figure 11. Detail of grommets for attaching apron.

Figure 12. Detail of the transfer tube attachment.

Figure 13. Weight, size, and total volume of these devices are easily handled by one man.

cut and sealed square, was angled at about 45° where the transfer tube was attached (Figure 12). The delivered weight was about 15 lb and packaged volume less than 2 ft^3. It was easily carried by one man (Figure 13).

The Katz Bag unit was fabricated from single-ply 1/8 in. count x 1/8 in. wide polyethylene fiber-reinforced polyethylene film with a total thickness of 9 mil. The seams were heat-sealed by a proprietary method, but the 3-in. diameter, 30-ft-long delivery tube was mechanically attached to the containment bag with an "O-ring" connection as an alternative to heat sealing.

Effort was made to simulate a spill-response working atmosphere during the demonstration to gain an insight into problems of deployment. Safety equipment was worn by the technicians, including respirators, safety glasses, hard hats, gloves, steel-toe safety boots, and chemically-resistant clothing. To minimize exposure, the spill source was approached only once by the technicians to attach the capture apron of the initial bag to the leaking tanker.

The technicians approached the tanker, with the simulated leak of 5 gpm in progress, dragged the apron of the Silco unit under the leaking hatch (Figure 14), and tied it into position (Figures 15 and 16). The delivery tube at the bottom of the unit was deployed uphill in order to serve as a valve. Figure 17 shows the unit in final position with approximately 200 gal of contained water.

After positioning the first unit, the Katz bag was placed in tandem below the first. This second unit was kept in reserve while the first was being filled. Because of the sloping conditions of the spill site, the first bag was only able to contain a little more than 500 gal of simulated spill. Figure 18 shows the liquid level in the bag at this point.

The field test was continued by transferring the accumulated spill liquid from the first unit into the second to verify the modular approach to collecting hazardous liquid from an accidental spill. The transfer tube of the first unit was maneuvered without loss of liquid to the apron of the second (Figure 19).

The spill test was continued with the simulated flow from the tanker increased to a rate of 15 gpm. Figure 20 shows the overall view of the spill site and bag deployment with about 850 gal captured. The transfer tube of the second unit was deployed upgrade to prevent liquid loss. The test was terminated when the two units combined contained more than 1000 gal. Figure 21 shows the condition of Bag No. 2 at this point. No leaks were evident in either bag.

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Figure 14. Field demonstration test - deploying the capture-and-containment device.

Figure 15. Field demonstration test - securing the device to the tanker.

Figure 16. Field demonstration test - detail of the apron, secured to collect leakage around the hatch.

Figure 17. Field demonstration test - Silco Industries device containing about 200 gal.

Figure 18. Field demonstration test - Silco Industries device containing about 500 gal.

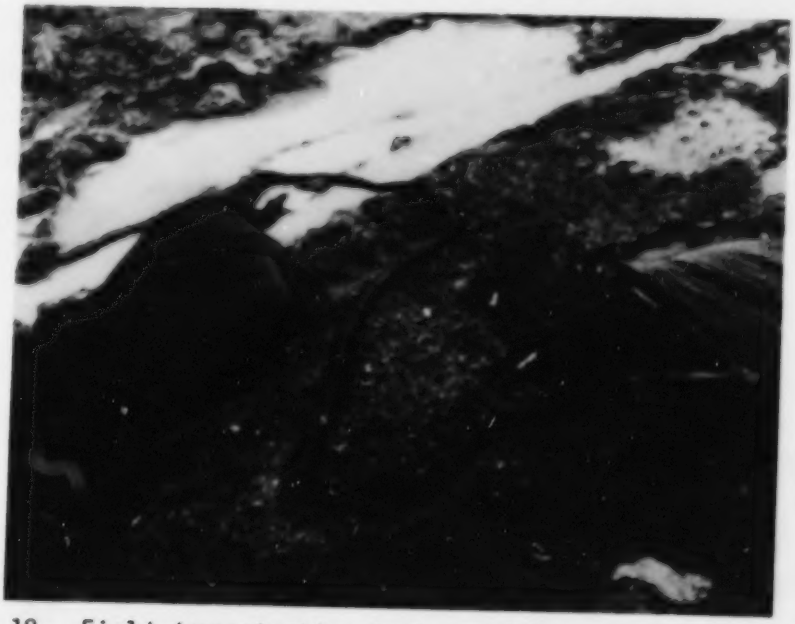

Figure 19. Field demonstration test - modular concept demonstrated.

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Figure 20. Overview of the field demonstration site with the two capture-and-containment devices deployed.

Figure 21. Detail of the Katz Bag Company device containing about 500 gal.

APPENDIX A

INVESTIGATION OF SURFACE SEALING SYSTEMS

GENERAL OUTLINE AND DESCRIPTION OF PROGRAM

The initial program was designed to select and evaluate sprayable sealing materials which could be employed in hazardous material spill situations and to design and fabricate a prototype application system. The planned program consisted of the following four phases:

1. Laboratory Studies
2. Pilot-Scale Testing
3. Prototype Fabrication
4. Field Demonstration.

Laboratory Studies

The first phase of the program consisted of the selection and evaluation of sealing materials which could fulfill the design goals. It included a survey and selection of sealant candidates and chemical compatibility studies and permeability tests that defined the capabilities and limitations of candidate sealing materials.

A portion of the work at the beginning of this phase also was dedicated to the selection of representative hazardous materials used in the compatibility tests.

Pilot-Scale Testing

The second phase of the program continued the evaluation of candidate sealing materials under conditions that simulated those of typical spill situations. The sealing capabilities of the more promising candidates were measured when they were placed on soil, stone, and grass substrates with equipment that could be used in accidental spill situations.

Prototype Fabrication

The third phase of the program was the design and fabrication of a prototype device which would best fulfill the objective of the program. This design concept was to be based upon the results obtained in the first two phases and was to be tested under simulated spill conditions to

determine areas for modification and parameters to be considered in the field demonstration.

Field Demonstration

The fourth phase of the program was to be a field test of the system on a spill of 10,000 gal of simulated hazardous liquid.

Phases 1 and 2 of the program were conducted as planned. At the conclusion of Phase 2, however, it was evident that sprayable systems were not the answer to the problem. As a result, the remainder of the original program was abandoned, and the emphasis placed on the capture-and-containment-bag concept described in the main body of this report.

This Appendix describes the spray sealant effort and presents the data that constituted the major portion of that program.

DISCUSSION OF CANDIDATE SEALANTS

Recent advances in the development of sealing materials have significantly increased the number of products commercially available. This, in conjunction with the broader scope of applicability available in these new products, made it mandatory to survey the field for sealing materials that could be considered candidates for this program.

The sealing materials which could be considered for sealing soil surfaces against intrusion by hazardous chemicals may be grouped into three general classes: Nonreactive, reactive, and surface-modifying chemicals. These classifications indicate the chemical formation of the sealant film and/or the interaction of the sealant with the substrate surface.

Nonreactive Sealants

Nonreactive sealants are those which have been previously polymerized and are dispersed or dissolved in either an aqueous or another solvent system. Such materials are primarily thermoplastic in nature, and include such materials as:

1. Bitumastic
2. Rubber
3. Acrylic
4. Cellulosic
5. Fluoroplastic
6. Phenolic
7. Polyester
8. Polystyrene
9. Polyvinyl chloride

Several of these materials can be used as aqueous dispersions, in which the aqueous media makes no contribution to health or safety hazards. These aqueous dispersions are subject to freezing, however, and film formation, which depends upon evaporation, reflects the influence of both temperature and air velocity. Household latex paints are typical examples; the rate of film formation is very slow at lower temperatures.

Solvent systems depend on evaporation of the solvent for film formation. Solvents or solvent systems other than water often have offensive odors or are flammable. Many solvents will contribute to the potential fire or health hazards when used in response to spills of hazardous chemicals.

The films prepared from any solvent systems are subject to pinhole formation, even on very well prepared substrates. When applied over rough or very porous substrates, formation of a continuous film becomes very difficult to accomplish.

Reactive Sealants

Reactive sealants are two or more component systems in which one component is reacted with a second component (often with a catalyst) to yield a polymer. Examples or this type of sealing material include:

1. Epoxy
2. Unsaturated polyester
3. Phenol/formaldehyde
4. Urea/formaldehyde
5. Urethane

Solvents are optional in the reactive materials listed above. Although the substrate may be at a lower temperature, the components of these systems have a minimum temperature for mixing the components and initiating the reaction. They are more likely to form films under adverse conditions (typical spill) than are the nonreactive systems.

Reactive sealant candidates with the ability to be foamed in place appeared to be particularly attractive. The foaming ability helped to eliminate pinholes, "shadowing" around larger debris, and the need for larger quantities of sealant to assure a continuous film. This "bridging ability," along with the resiliency and chemical compatibility of the foam, made polyurethanes good candidates.

The advantage of foamed materials can also be demonstrated by comparing the weights of any sealant required to cover a 1200 ft^2 area as a function of the application rate and flow density. These data are summarized in Table A-1, which compares the total weight, application rate, and approximate thickness for various foamed sealant densities.

TABLE A-1. TOTAL SEALANT WEIGHT AS A FUNCTION OF APPLICATION RATE AND SEALANT THICKNESS

Application Rate (lb/ft^2)	Weight of Sealant Required ($lb/1200\ ft^2$)	Coating Thickness (in.) at Coating Density of ($3\ lb/ft^3$)	($20\ lb/ft^3$)	($60\ lb/ft^3$)
0.03	36	0.12	0.02	0.006
0.06	72	0.24	0.04	0.012
0.10	120	0.40	0.06	0.020

Although foam expansion to 3 lb/ft^3 does not appear to be practical at these low application rates, a sealant density of 20 lb/ft^3 will generate a much thicker film with a greater possibility for sealing than the unfoamed materials at approximately 60 lb/ft^3. The latter results in only a 6-mil film at an application rate of 0.03 lb/ft^3 (the normal thickness for polyethylene film) and about a 20-mil-thick film for an application rate of 0.10 lb/ft^3.

Repellent Chemicals

The third sealant type consists of repellent chemicals which, when applied to surfaces, modify the surface characteristics such that the surfaces are not penetrated.

Extensive repellent technology has been developed for four classes of materials: textiles, paper, leather, and masonry. In each, there is a broad range of techniques and chemical systems but only two classes of chemicals -- silicones and fluorocarbons -- appeared promising for the proposed use. These are used to provide the so-called durable finishes on textiles, those that are essentially unaffected by either laundering or dry cleaning.

Silicone systems are employed either alone or in combination with melamine or urea-formaldehyde crease-proofing resins. For optimum properties, these require some crosslinking, usually accomplished in the textile industry with a short-term, elevated temperature (150°F) cure.

The most widely used materials are perfluoro-derivatives of the polyacrylates. Marketed under tradenames such as Scotchgard, Zepel, and the U.S. Army's Quarpel, they are available as emulsions or dissolved in organic solvents for spray application.

CONCLUSIONS

Candidates of each classification were subjected to testing, including film-forming ability under various conditions, chemical compatibility

against selected hazardous chemicals, and film cure at various temperatures. The application equipment requirements for each were also investigated.

The use of sprayable, film-producing chemicals for the onsite sealing of soils was not practical. Applying the film-forming systems to substrates likely to be found on berms and ditches near highways and railways produced films that leaked or allowed seepage underneath.

A summary of the results for the three classifications is as follows:

(1) Nonreactive materials, those which have been previously polymerized and are dispersed or dissolved in either an aqueous or other solvent, had the following faults:

   (a) They are often subject to freezing and deactivation during storage or when applied.
   (b) Film forming at lower ambient temperatures can be very slow.
   (c) Film forming at higher ambient temperature can be too fast.
   (d) When formulated with organic solvents, these systems require evaporation, which poses a fire or health hazard.
   (e) Film formation often results in pinholes in the film as the solvent evaporates.
   (f) Leak-free film formation was not possible over rough terrain and vegetation. A very uneven film with shadow areas having little or no film results.

(2) Reactive systems, composed of two or more components that are reacted onsite to yield a polymer are more likely to form films under adverse weather conditions, but have several problems:

   (a) These systems cannot be used on snow, ice, and wet surfaces; the spilled liquid generally lifts the film and flows underneath.
   (b) Holes in the film occur when the film is formed on top of snow, ice, or water.
   (c) Applications to vegetated areas produce films that do not penetrate to the soil below and that leak badly.
   (d) Even on well-prepared substrates, pinhole-size voids are commonplace in the films.

(3) Repellent chemicals that modify the surface characteristics of materials such that the surfaces are not penetrated by liquids simply were not effective on soils. Silicone and fluorocarbon repellent chemicals were evaluated with similar observations.

LABORATORY INVESTIGATION

The laboratory investigation of potential sealing materials was taken through a series of tests designed to outline their capabilities and the possibility for fulfilling the objective of the program. The test sequence progressed from the subjective data obtained in the initial survey to

pilot-scale tests.

This phase of the program evaluated each candidate in terms of the conditions required to form a continuous seal, chemical compatibility of the film with representative hazardous chemicals, and permeability of the film to liquid chemicals. The tests were made under controlled conditions for comparison of the various types of sealing materials, and to delineate operating conditions which could be used for the design of field tests and equipment.

Selection of Sealant Candidates

Manufacturers of the various sealant candidates were contacted by phone and a follow-up letter to obtain detailed information on the possible use of their materials for this application under the conditions and application technique required for the final system. In addition, the current literature was surveyed for materials advertised as sprayable coatings for any application, and the manufacturers of such materials also were contacted with the same guidelines used above. Table A-2 lists the manufacturers contacted and the sealant considered as one of their special commercial products. Over 40 manufacturers were contacted.

Every effort was made to contact people knowledgeable of the chemistry of each company's system, generally talking to research personnel rather than sales representatives to assure an accurate appraisal of the candidate's performance under adverse conditions.

Samples were requested for a preliminary evaluation if, in the opinion of us or the supplier, the candidate could meet the following broad criteria:

- A proven ability to form a continuous film.
- Sprayable under conditions practical for a portable system, or could be made so with minor modification to the formulation.
- Able to form a protective skin on the film in a reasonable time period. Fifteen min at moderate conditions appeared reasonable.
- No serious threat in itself to the operator or the environment.

Manufacturers' compatibility data were essentially ignored since most such data are based on and intended for long-term exposures, whereas this intended use was short-term. Conditions such as blistering or swelling, which may affect a sealant's use in other applications, were of little hindrance to its use as a barrier to penetration of a chemical into the substrate.

Candidate sealants were screened by either spraying or brushing the materials on a cardboard backing. Physical properties and set times were observed, and the more promising candidates were exposed to a selection of hazardous chemicals under a foot of head pressure. This was accomplished by simply sealing a foot-long section of glass tube to the coated cardboard with a silicone caulking as a sealant at the interface, and introducing the test hazardous chemical into the tube.

TABLE A-2. LISTING OF SEALANT CANDIDATE MANUFACTURERS

Contact	Potential Sealant
American Cyanamid Company	Urea/formaldehyde
Anderson Development Company	Silicones
Ashland Chemical Company	Urethanes
Atlas Minerals and Chemicals	Adhesives
Borden Chemical Company	PVC copolymers
Callery Chemical Company	Urethanes
Carboline Company	Vinyl paint
Ceilcote Company	Bitumastic and polyester
Clintwood Chemical Company	Surfactants
Corrosioneering, Inc.	Epoxies and polyesters
Dow Chemical Company	Epoxies
Dr. Leonard Spialter	Silicones
duPont Specialty Chemicals	Fluorosurfactants
E S B Incorporated	Adhesives
General Electric	Silicones
Goodloe E. Moore	Adhesives
Hooker Chemical Company	Phenol/formaldehyde
Irathane Systems, Inc.	Urethanes
Johns-Manville	Ceramic adhesives
Koppers Company	Polyesters
Lastek Paint, Inc.	Bitumastic coatings
Locktite Corporation	Adhesives
Mameco, International	Urethanes
Midland Adhesive and Chemical Corporation	Epoxies
Oneida Electronics Corporation	Adhesives
Orb Industries, Inc.	Aerosol adhesives
Palmer Adhesives	Adhesives

(continued)

TABLE A-2. LISTING OF SEALANT CANDIDATE MANUFACTURERS
(continued)

Contact	Potential Sealant
PPG Industries	Polyesters
Pocono Fabricators, Inc.	Cements
Pullman-Kellogg Company	Fluorocarbons
Protex-a-Cote	Coatings
P.V.O. International	Proprietary aqueous system
Randustrial Corporation	Urethane sealer
Royal Industries	Fluorocarbons
Sauereisen Cements Company	Cements
Shell Chemical Company	Surfactants, epoxies
Shiloh Specialty Company	Sealants
Tracor, Inc.	Previous work
3M Company	Polyesters, surfactants, and urethanes
Trowelon, Inc.	Polyesters
Union Carbide	Polyphenol and phenol/ formaldehyde

The preliminary challenge chemicals were water, sulfuric acid, sodium hydroxide, trichloroethylene, methanol, naphtha, and methyl ethyl ketone. Conclusions as to the utility of the specific sealants based on the results of exposure to these challenge chemicals are summarized in Table A-3. Failure of the sealant coating generally was catastrophic with loss of liquid. For those cases where failure was observed, similar chemicals in the classification were tested for verification. Those considered for further testing generally passed all preliminary tests.

Although representatives of all 13 sealant types were evaluated, promising candidates were limited to only four of these. They were:

Adhesives	Borden Chemical Company's Polyco 2607
Urethanes	Callery Chemical Company's Resin 115
	Ashland Chemical Company's EP 65-86/88
Surfactants	duPont deNemours' Zonyl RP
	Clintwood Chemical Company's Clindrol 100CG
Plastic Sheeting	--

In general, it was felt that aqueous sealants, repellent chemicals, and adhesives required additional experimental testing to provide more complete data for evaluation. For the reactive sealant candidates, only the urethane systems were found to combine most of the characteristics required of the sealing materials for this program. The epoxy systems were found to have excellent chemical compatibility when exposed to the challenge liquids, but required special care in setting the component ratios and thick layers for suitable field application. Polyester systems were, generally, quite easily sprayed, but had severe temperature and chemical compatibility limitations. One silicone formulation was found which could be considered for field applications, but high viscosity and limited chemical compatibility would restrict its sealing capabilities.

Several commercial urethane formulations were found to be generally applicable for the intended use. The considered opinion concerning their use was that foaming formulations would provide the best combination of characteristics to fulfill the objective.

Several types of plastic sheeting were found to have general applicability for the intended use. The initial attitude concerning their use in this program, however, was that they were not of primary interest, and that sprayed systems were to be emphasized. This attitude was later revised and polyethylene sheeting in the form of bags became the main thrust of the program.

At a later point in the program, since polyethylene film proved to have such excellent compatibility against most challenge agents, polyethylene and polypropylene prepolymers were tested as a sprayable film. These were obtained as low melting waxes that were melted and sprayed on a substrate to cool and form a film.

TABLE A-3. SURVEY OF SEALING MATERIALS

Sealant Type	Company	Product Name	General Performance	Conclusions & Observations
Adhesive	Goodloe E. Moore	Tuff-Bond 35	Questionable	Unacceptable compatibility
		Tuff-Bond 66	Questionable	Unacceptable compatibility
		Quick Set	Questionable	Unacceptable compatibility
	Oneida Electronics	Instant Weld	Poor	Unacceptable compatibility
	Borden Chemical	Polyco 2445	Good	Questionable
		Polyco 2186	Good	Unacceptable
		Polyco 2607	Good	Acceptable; slow degradation
	Johns-Manville	Ceramic Adhesive	Questionable	Unacceptable; cure conditions
Acrylic	Emerson & Cuming	Eccocoat AC-8	Questionable	Unacceptable compatibility
Paint	Cole-Parmer	Malgene	Questionable	Unacceptable compatibility
	Carboline	Versikote 54	Questionable	Unacceptable compatibility
Silicone	General Electric	85-1693 A/B	Poor	Unacceptable compatibility
	Dow Corning	3-5000	Questionable	Unacceptable compatibility
Urethane	Irathane Systems	Irathane 149-C/R	Questionable	Unacceptable viscosity and compatibility
	Mameco Internat'l	Vulkem-205	Good	Unacceptable viscosity
	Randustrial	P-250	Questionable	Unacceptable compatibility
Urethane	Metalcrete Mfg.	Vulcanox	Good	Unacceptable viscosity
	Callery Chemical	115	Good	Acceptable
	Ashland Chemical	6100/6300	Questionable	Poor filming
		EP 65-86/88	Good	Acceptable
Surfactant	duPont	Sample kit	Questionable	Unacceptable compatibility
		Zonyl RP	Good	Questionable
	Clintwood Chemical	Clindrol 100CG	Poor	Unacceptable compatibility
Polyester	Ceil-Cote	Flakeline 252	Good	Unacceptable viscosity
	Koppers	1070 Resin	Questionable	Unacceptable compatibility

(continued)

TABLE A-3. SURVEY OF SEALING MATERIALS (continued)

Sealant Type	Company	Product Name	General Performance	Conclusions & Observations
Aqueous (two component)	Pacific Anchor Div. P.V.O. Internat'l	Chem-Cure	Questionable	Questionable
Epoxy	Corrosioneering	Resista-Flake 4200	Questionable	Questionable; thick coatings required
Urea/ formaldehyde	American Cyanamid	--	Questionable	Unacceptable; added pollution
Phenol/formaldehyde	Hooker Chemical	--	Questionable	Unacceptable; added pollution
Plastic Films & Sheeting	Aero-Tec	Polyurethane	Good	Acceptable
		Polyethylene	Good	Acceptable
		Polypropylene	Good	Acceptable
	Allied Chemical	Foamed Polyethylene	Good	Unacceptable; hot preparation required
	Foamed Polypropylene		Good	Unacceptable; hot preparation required
		Foamed Polystyrene	Questionable	Unacceptable; compatibility
Cement	Pocono Fabricators	--	--	--

Selection of Representative Hazardous Materials for Challenge Agents

Recent growth in the use and transport of chemicals has significantly complicated the selection of materials for representative challenge agents. The number of commercial chemicals and the degrees of hazard which they may present to the public or the environment make this selection difficult, at best. Selecting the materials to be used for evaluating and developing a system for sealing soil surfaces required a thorough search and judicious analysis of data generated in many diverse areas.

The selection of representative hazardous materials was made from data published by chemical manufacturers, safety associations, and both government and insurance agencies. These sources were used to select 30 chemicals to represent those that are transported in bulk and that would, if spilled, present a significant threat to ground water supplies in the area. These materials are presented in Table A-4, which includes representatives from most chemical classes.

Data, such as the quantity transported, relative hazards such as TLV (Theshold Limit Value), LC (Lethal Concentration), and LEL (Lower Explosive Limit), spill probabilities, and biodegradability were used as criteria in selecting these chemicals. When overall ratings were similar for several candidates, the final selection was based upon chemical aggressiveness toward containment systems.

A typical example may be shown for the inorganic acids class. Sulfuric acid is an obvious choice, based on the quantity which is transported. Nitric and arsenic acids were possible second choices. Although it was recognized that arsenic acid represents a greater pollution hazard, nitric acid was chosen because of its greater chemical reactivity toward most sealing materials. The logic in the selection was that any system capable of containing nitric acid would also contain arsenic acid.

Sodium hydroxide was chosen to represent all three major inorganic bases: sodium, potassium, and ammonium hydroxides. All are aqueous solutions posing essentially the same reactivity and thus containment problem.

Phosphorus trichloride is a typical liquid inorganic halide transported. We have not included any solids, such as aluminum chloride, as challenge agents even considering that in a rain water-soluble solids might be considered a hazard. We believe that in a rain, where solids could be a problem, the obvious solution is to place a protective cover over the spilled chemical.

We chose phosphorus oxychloride as our inorganic oxidizer representative, although nitric acid also would be classified as such. Silicon oxychloride was an alternative choice. Others are also handled in bulk -- namely hydrogen peroxide, calcium hypochlorite, and sodium bichromate.

Carbon disulfide was chosen as the organic sulfur derivative because of its solvent properties.

TABLE A-4. PRIMARY REPRESENTATIVE HAZARDOUS CHEMICALS

Inorganic acid: Sulfuric Nitric	Alcohol Isopropanol Cresols
Inorganic base: Sodium hydroxide	Ester: Ethyl acetate Ethyl acrylate
Inorganic halide: Phosphorus trichloride	Amine: Ethanolamine Pyridine
Inorganic oxidizers: Phosphorus oxychloride	Ketone: Acetone Methyl ethyl ketone
Organic acids: Acetic Acrylic	Mixed solvent: Naphtha Turpentine Lacquer solvent
Organic halide: Methylene chloride Trichloroethylene	Mixed hydrocarbons: Gasoline Kerosene
Aldehyde: Acetaldehyde Benzaldehyde	Aromatic: Toluene Xylene
Plastic monomer: Styrene Vinyl acetate	

Two organic acids were selected -- acetic and acrylic. Acetic acid has the most spill potential. Acrylic, on the other hand, has a significant potential for spills based on intra-plant transport and poses a tougher containment problem.

Methylene chloride and trichloroethylene, because of their excellent solvent properties, were chosen to represent the organic halides.

An organic sulfur representative was not included. The mercaptans are transported in bulk, but present no unusual solvent or reactivity properties.

Acetaldehyde, benzaldehyde, and acrolein were selected over furfural, butyraldehyde, and formaldehyde. Each candidate has either high spill potential or poses a difficult problem to the sealant.

Isopropanol and a cresol were selected over ethylene glycol and allyl alcohol.

Herbicides and pesticides were not selected as challenge agents. To our knowledge, none are transported as bulk liquids and, when formulated as liquids, are either in aqueous or hydrocarbon solution. Thus these classifications are best represented by the solvent.

Ethyl acetate and ethyl acrylate were chosen to represent esters. Vinyl acetate and methyl methacrylate are possible alternatives.

Ethanolamine and pyridine were chosen over acrylonitrile and aniline as organic nitrogen derivatives. All are good choices, but ethanolamine and pyridine present fewer problems in laboratory handling than acrylonitrile and aniline.

For ketones, acetone and methyl ethyl ketone were selected.

Mixed solvents pose a significant hazard to most sealant membranes. Naphtha, turpentine, and lacquer solvent were selected -- the latter consisting of a mixture of acetates and ketones.

Gasoline and kerosene were chosen to represent mixed hydrocarbons as a class. Other alternatives include JP-4 and cyclohexane.

Of the aromatics, toluene and xylene appear to be good representatives. Possible alternatives are phenol and tetrahydronaphthalene.

In a last category, styrene and vinyl acetate were selected as plastic monomer candidates that have a high spill potential and pose unique reactivity problems.

Laboratory Test Procedure

The sealing materials selected from the survey as potential candidates were tested for their sprayability, film-forming capability, and chemical compatibility. These tests were carried out in conjunction with the manufacturer to test each sealant under its optimum conditions for good film formation using suitable equipment, conditions, and optimum ratios of components.

Sprayability Tests --

Sprayability tests were conducted in a small spray chamber, a schematic of which is shown in Figure A-1. The unit consisted of a variable-speed belt conveyor with a speed range of 20 to 120 ft/min, a spray gun with supporting and controlling equipment, and a vented spray cabinet for controlling fumes and overspray. All fumes were exhausted through an activated charcoal filter to capture organic vapors.

The spray gun varied with the sealant. Single-component sealants were applied using a single-component DeVilbiss Model 504 flat spray gun. Two-component sealant candidates were applied with a Binks Model 18 FMA gun, which also provides a flat spray pattern. The Binks gun, which includes an internal mixing chamber, is especially required for the two-component urethane sealant candidates because of short cure times. Spray rates were kept nearly uniform throughout at about 1 to 3 lb/min, and application rates held in the range of 0.02 to 0.1 lb/ft^2. These rates are considered in the probable range of the final piece of equipment.

The substrate was asbestos paper about 0.012 in. thick, which provided a uniform surface for good film formation and a porous substrate for subsequent compatibility testing. Six-in.-diameter sprayed samples were prepared and then mounted in the gas pressurization and compatibility test units for evaluation.

Initial attempts to spray the candidate were done with flowmeters in the system to measure and monitor all the liquids. After establishing the precision of flows and stoichiometry, the liquid flows were calibrated by weight and assumed to be constant throughout the 3 to 5 min experimental spraying times.

Gas pressurization was considered the best means for delivering and metering the sealants. Between 50 and 90 psig was used in the tanks containing the sealants to obtain the desired flow rates. In addition, about 1 to 2 cfm air was added at the nozzle to supply atomization air to help set the spray pattern. A "flat V" pattern was found to produce uniform application rates on sample surfaces.

Compatibility Tests --

Tests were conducted initially on small, provisional samples and, later, with the chemical compatibility test unit shown in Figure A-2.

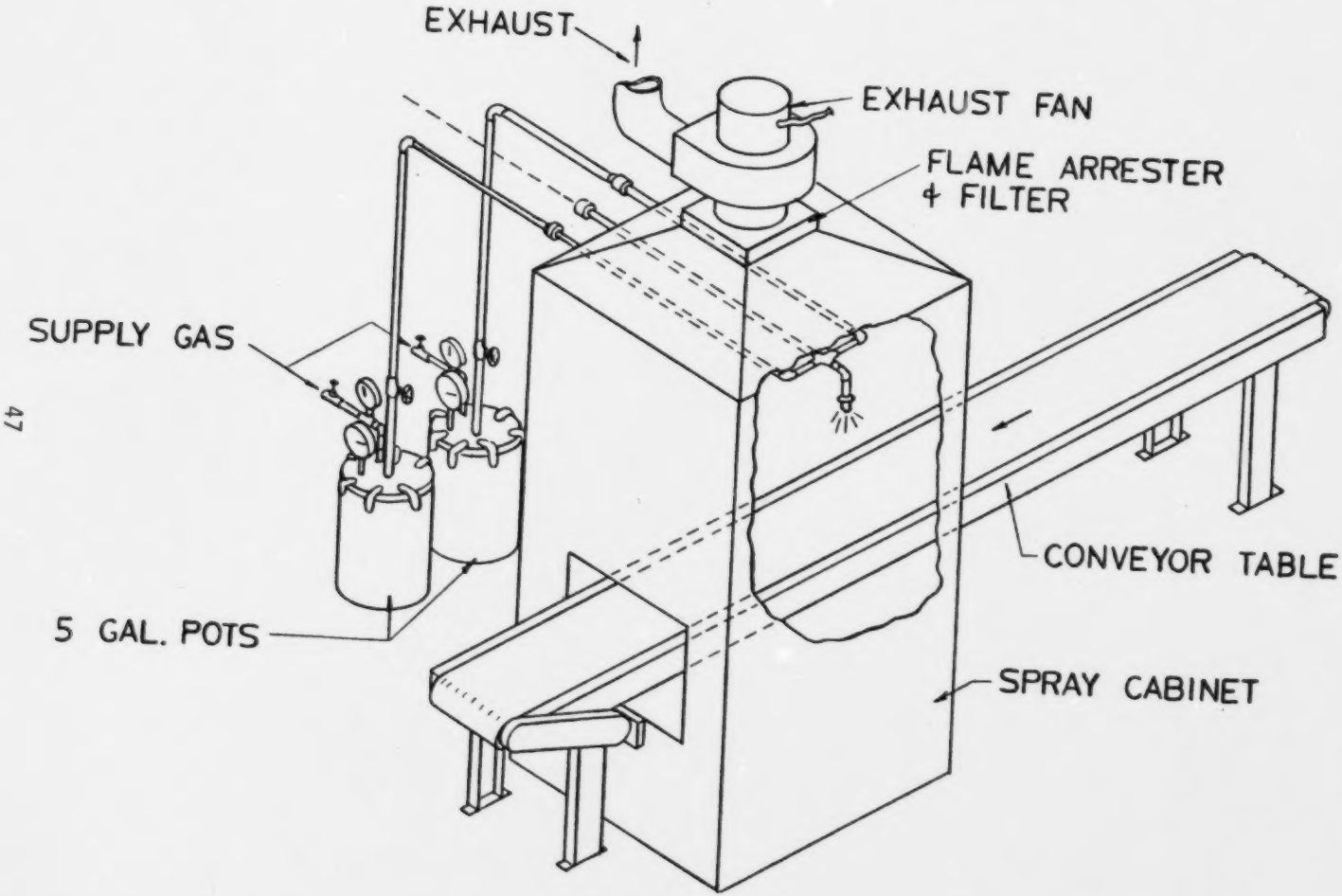

Figure A-1. Schematic of spray chamber

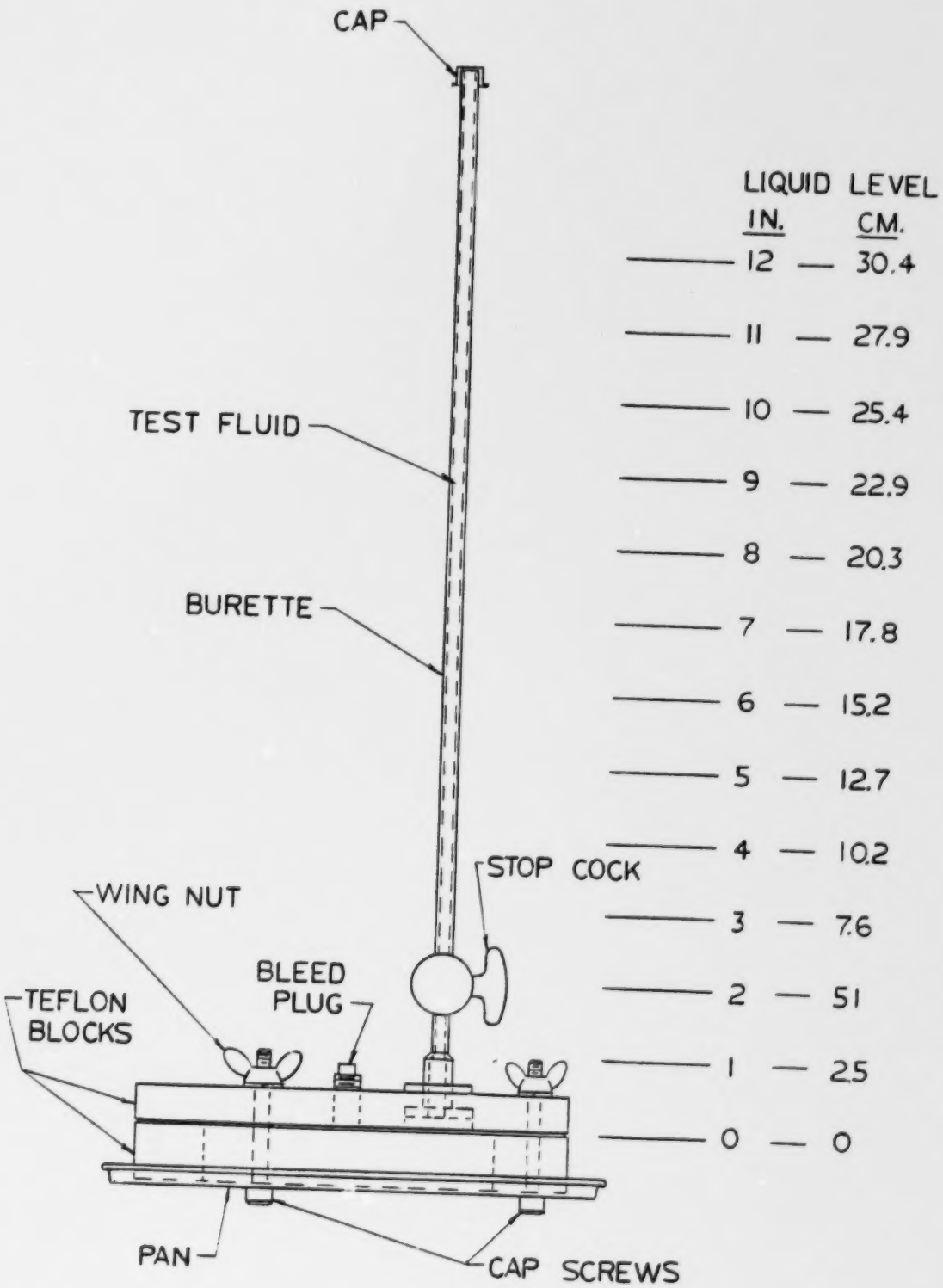

Figure A-2. Compatibility test unit

This apparatus, fabricated from Teflon stock, was designed to expose a large surface area of sealant (12.5 in^2) to a 1 ft head of challenge liquid, while using only a minimum volume of chemical. The inside of the top section was domed for gas escape and exposure of liquid to the total sealant surface. The mating base section is an open cylinder, with a 4 in. inside diameter. A metal pan was used as a solid base for handling. An O-ring, not shown in the schematic, was placed between the two halves of the Teflon unit to achieve a seal.

The total volume of liquid required to achieve 1 ft of head was between 30 and 40 ml. Based on a liquid volume size 4 in. in diameter and 12 in. high, an allowable leak rate for a 24-hr period was approximately 5 ml/hr or a total loss of 120 ml. In practice, sand was used in the hollow base as a backing for the asbestos paper/sealant candidate combination. The void volume in the sand to retain liquid which penetrated the sealant was approximately 75 ml.

Film Forming Capability --

The integrity of the film was evaluated by measuring the leak rate of air through the cured sample mounted in the base of the compatibility test unit prior to the addition of challenge agent. The apparatus, shown in Figure A-3, allowed pressurization to a 12-in. water head.

Test Procedure --

The test procedure was as follows: Conditions were set up and checked (flow rates, stoichiometry, conveyor speed, and spray pattern) on the spray equipment to achieve a suitable film for the sealant under study at the desired application rate. With the asbestos substrate on the base of the compatibility test unit and preconditioned to the desired temperature, the samples were placed on the moving conveyor and the sealant applied. They were then returned to the design temperature condition and the curing rate monitored.

The tests were conducted in multiples of 4 to 8 units. This number allowed individual monitoring of cure time, and also allowed us to assemble the compatibility test apparatus and to expose the film to the challenge liquid in a reasonable time period (15 to 30 min).

After assembly of the compatibility test apparatus and before the addition of challenge chemical, the integrity of the film and seal was tested against gas pressure. Generally, acceptable samples leaked in the range of 0 to 2 in./min of water. Samples that leaked at a rate greater than 4 in./min were not subjected to the challenge chemical.

The hazardous challenge chemicals were added to the test unit to a 12 in. head in a fume hood. The leak rate was monitored in the burette continuously during the first hour, and at intervals throughout the remainder of the day. Lost liquid was replaced periodically to maintain a 12 in. head.

The test period was scheduled to run overnight, during which the samples were unattended. If the samples exhibited a leak rate within the

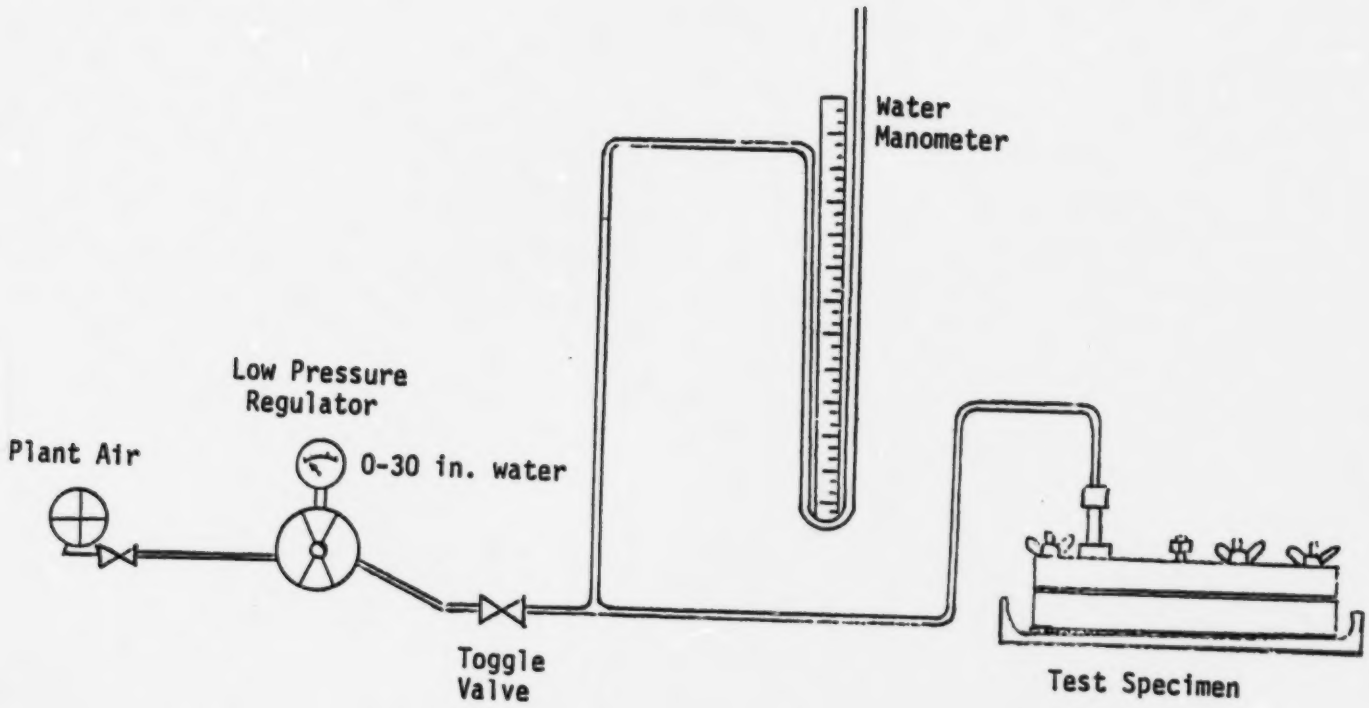

Figure A-3. Air pressurization apparatus used to screen test specimens

allowable limit (approximately 5 ml/hr) they were left exposed. Those with leak rates in excess of 5 ml/hr had the liquid head removed by closing the stopcock, and the head replaced in the morning to obtain additional approximate data.

For comparison, the leak rate data are reported as Total Liquid Transmission for 24 hr (ml/24 hr). This required extrapolation of short term test data to 24 hr for the many samples with high leak rates.

All samples, whether failures or successes, were opened in the hood and checked for visible changes. Holes were usually noticeable in test films which failed. Even successful runs often had discoloration, blisters, and swelling, indicative of some attack by the chemical.

Discussion of Test Results

Results with Adhesives --

This general classification contained many chemical types, but most were eliminated in the preliminary survey due to a known lack of chemical compatibility. Latex adhesives were the exception and required further testing. A Borden system, Polyco 2607, was found that formed a film within minutes and was shown to be compatible with many organic materials. Samples of this were tested on asbestos paper substrates. The results are compiled in Table A-5.

Results with Repellent Chemicals --

The preliminary survey of potential sealing materials revealed that some materials in this classification may have the ability to modify the surface characteristics of the substrate and reduce penetration by hazardous materials. The survey concluded that two types, fluorinated polyacrylates and superamides, were potential candidates.

Several commercial samples received some experimental investigation, but only two, E. I. duPont's fluorinated polyacrylate "Zonyl RP" and Clintwood Chemical's superamide "Clindrol 100CG," were subjected to tests. Neither showed any significant sealing ability when applied on sand substrates at rates between 0.01 and 0.05 g/cm^2, even against water. On asbestos, however, some sealing ability was demonstrated for a limited time. The results for Clindrol are shown in Table A-6.

The liquid transmission rates represent 30 to 80% reductions over untreated substrates for the limited times shown; however, the samples appeared to show a general solubility of the Clindrol 100CG in the challenging liquids. When the coating was dissolved, transmission of the liquid occurred at the same rate as with untreated paper.

The results for Zonyl RP are summarized in Table A-7. Though more promising than Clindrol, neither it nor Clindrol would be a practical sealant for field applications.

TABLE A-5. RESULTS OF COMPATIBILITY-PERMEABILITY TESTS WITH BORDEN CHEMICAL COMPANY LATEX "POLYCO 2607"

Challenge Liquid	Application Conditions				Total Liquid Transmission (ml/24 hr)
	Approximate Temperature, °C	Substrate Condition	Application Rate (g/cm^2)	Approx. Cure Time(min)	
Gasoline	21	dry	0.03	5	13.4
Methylene chloride	21	dry	0.03	5	5.0
Lacquer solvent	21	dry	0.02	5	5.3
Styrene	21	dry	0.03	5	0.3
Carbon disulfide	21	dry	0.03	5	19.5
Phosphorus oxychloride	21	dry	0.03	5	15.0
Xylenes	21	dry	0.02	5	1.2
Cresol	21	dry	0.02	5	1.3
Methyl ethyl ketone	21	dry	0.03	5	35.3
Naphtha	21	dry	0.03	5	3.9
Sodium hydroxide (5N)	21	wet	0.03	15	3.4
Acetaldehyde	21	wet	0.03	15	69.6
Sulfuric acid	21	wet	0.05	15	2.1
Monoethanolamine	21	wet	0.03	15	1.4
Isopropanol	21	wet	0.03	15	5.4
Vinyl acetate	21	wet	0.03	15	11.9
Phosphorus trichloride	21	wet	0.03	15	14.3
Water	3	dry	0.03	60	20.5
Vinyl acetate	3	dry	0.03	60	11.0
Naphtha	3	dry	0.03	60	93.6
Naphtha	3	dry	0.02	60	6.0
Gasoline	3	wet	0.03	180	15.5
Sodium hydroxide (5N)	3	wet	0.03	180	66.2
Water	3	wet	0.03	180	56.8
Methylene chloride	3	wet	0.04	180	18.0
Sulfuric acid	3	wet	0.04	180	37.1
Cresol	3	wet	0.04	180	1.8
- -	<0	no cured seal obtained with ten samples			

TABLE A-6. TEST RESULTS OBTAINED FROM SAMPLES OF "CLINDROL 100CG"

Challenge Liquid	Average Liquid Transmission Rate (ml/min)	Breakthrough (min)
Benzaldehyde	3 to 4	5
Naphtha	2 to 4	20
Trichloroethylene	4 to 5	5

Urethane Foam Systems Results --

Callery Chemical's Resin 115 and Ashland Chemical's EP 65-86/88 were further tested as representative urethane foam candidates. Application rates between 0.02 and 0.12 g/cm^2 were tested on asbestos after it was established in preliminary tests that rates in excess of 0.02 g/cm^2 were necessary to seal the sand surface. The compatibility test results are summarized in Tables A-8 and A-9.

Polyethylene Prepolymer Results --

The chemical compatibility of polyethylene with many hazardous chemicals was considered a definite attribute for its use as a sealing material. A thorough search of commercial forms of polyethylene revealed that low-density polymers are available which could be used to form a film in situ. These materials, often referred to as polyethylene waxes, have the characteristic low softening points and low viscosities commonly associated with natural waxes. The possibility of spraying polyethylene, with prior heating, was investigated as well.

Three samples of these materials were supplied by Allied Chemical Company. Some selected properties of them are listed in Table A-10.

The visco-elastic flow properties of these materials make the softening point and melt viscosity important factors in the choice of materials for a spray application. Lower softening points tend to lower the system operating temperature, which means that evaporation of all system components will be minimal. Lower melt viscosities tend to reduce the power requirements for spraying, which translates into payload and cost savings. Both of these are desired, but unfortunately the capacity for forming continuous films is inversely related to softening point, viscosity, and density of polyethylene polymers.

TABLE A-7. RESULTS OF COMPATIBILITY-PERMEABILITY TESTS WITH E. I. DUPONT De NEMOURS SURFACTANT "ZONYL RP"

Challenge Liquid	Application Conditions			Total Liquid Transmission (ml/24 hr)
	Approximate Temperature, °C	Substrate Condition	Application Rate (g/cm^2)	
Trichloroethylene	22	dry	0.03	8
Trichloroethylene	22	dry	0.03	140
Gasoline	22	dry	0.03	5
Vinyl acetate	22	wet	0.03	3
Acetic acid	22	dry	0.03	>1000
Water	22	dry	0.03	380
Water	22	dry	0.02	225
Naphtha	22	dry	0.03	9
Trichloroethylene	25	wet	0.003	60
Acetic acid	25	wet	0.003	>1000
Vinyl acetate	25	wet	0.02	43
Naphtha	25	wet	0.02	19
Water	25	wet	0.02	6
Acetic acid	25	wet	0.02	275
Ethyl acrylate	22	wet	0.01	25
Monoethanolamine	22	wet	0.01	63
Cresol	22	wet	0.01	13
Gasoline	22	wet	0.003	7
Methylene chloride	22	wet	0.003	7
Benzaldehyde	22	wet	0.003	28

TABLE A-8. RESULTS OF COMPATIBILITY-PERMEABILITY TESTS WITH CALLERY CHEMICAL COMPANY URETHANE "115" FORMULATION

Challenge Liquid	Application Conditions				Total Liquid Transmission (ml/24 hr)
	Approximate Temperature, °C	Substrate Condition	Application Rate (g/cm^2)	Approx. Cure Time(min)	
Acrolein	22	dry	0.02	2	19.1
Carbon disulfide	22	dry	0.02	2	4.9
Pyridine	22	dry	0.02	2	8.7
Sodium hydroxide (5N)	22	dry	0.02	2	12.7
Gasoline	22	dry	0.05	2	0
Phosphorus trichloride	22	dry	0.05	2	8.2
Phosphorus oxychloride	22	dry	0.05	2	14.2
Cresol	22	dry	0.05	2	11.3
Acetaldehyde	22	dry	0.05	2	44.5
Carbon disulfide	22	dry	0.02	2	4.9
Monoethanolamine	22	dry	0.03	2	2.1
Sulfuric acid	20	dry	0.05	2	4.2
Trichloroethylene	20	dry	0.05	2	2.4
Benzaldehyde	20	dry	0.05	2	21.1
Acetone	20	dry	0.05	2	failed
Methylene chloride	20	dry	0.12	5	23.0
Ethyl acrylate	20	dry	0.12	5	6.3
Acetic acid	20	dry	0.12	5	7.7
Styrene	20	dry	0.03	1	2.1
Methylene chloride	-5	wet	0.04	25	7.6
Isopropanol	-5	wet	0.04	25	0
Acetone	-5	wet	0.05	10	30.0
Cresol	-5	wet	0.05	10	2.3
Xylene	-5	wet	0.04	10	1.6
Gasoline	-5	dry	0.05	5	5.9
Sodium hydroxide (5N)	-2	wet	0.04	25	3.6
Benzaldehyde	-2	dry	0.04	15	5.1
Trichloroethylene	-3	wet	0.05	20	4.8
Sulfuric Acid	-3	dry	0.07	10	14.5
Vinyl acetate	-3	wet	0.05	20	20.9
N,N -Dimethylformamide	-5	wet	0.05	20	failed after 2.5 hr

TABLE A-9. RESULTS OF COMPATIBILITY-PERMEABILITY TESTS WITH ASHLAND CHEMICAL COMPANY "EP65-86/88"

Challenge Liquid	Application Conditions			Total Liquid Transmission (ml/24 hr)
	Approximate Temperature, °C	Substrate Condition	Application Rate (g/cm^2)	
Water	26	dry	0.06	6.9
Sulfuric acid	25	dry	0.02	153
Sodium hydroxide (5N)	25	dry	0.02	377
Phosphorus trichloride	25	wet	0.02	7.0
Phosphorus oxychloride	25	dry	0.04	1.2
Carbon disulfide	25	dry	0.04	28.7
Acetic acid	20	dry	0.02	3.5
Methylene chloride	25	dry	0.09	29.6
Trichloroethylene	25	dry	0.06	2.0
Benzaldehyde	25	dry	0.08	9.4
Isopropanol	20	dry	0.02	6.6
Cresol	25	dry	0.04	2.8
Ethyl acrylate	20	dry	0.05	11.7
Monoethanolamine	25	dry	0.04	1516
Acetone	20	dry	0.05	15.6
Methyl ethyl ketone	26	dry	0.06	5.5
Naphtha	20	dry	0.06	3.5
Lacquer solvent	25	dry	0.04	10.9
Gasoline	25	dry	0.04	7.7
Kerosene	20	dry	0.06	2.0
Vinyl acetate	25	dry	0.04	13.6
Sulfuric acid	0	dry	0.04	> 1
Methylene chloride	0	wet	0.04	20.1
Methyl ethyl ketone	0	dry	0.04	46.7
Carbon disulfide	-5	dry	0.04	9.7
Cresol	-5	dry	0.04	2.5
Monethanolamine	-5	dry	0.04	4.6
Lacquer solvent	-5	wet	0.04	8.8
Sodium hydroxide (5N)	-5	dry	0.04	100
Gasoline	-5	dry	0.04	30.3
N,N-Dimethylformamide	-5	wet	0.04	[~45 ml/hr]

A secondary objective of these tests was to determine some general trends in the comparison of softening points, viscosities, and composition. Such a comparison was possible since the polymers are mutually miscible, forming mixtures with intermediate properties.

Three tests we made using combinations of the three polymers which had softening points between 90 and 105°C. The mixtures were placed in a steel cylinder, heated and shaken to form a homogeneous liquid, pressurized

TABLE A-10. SELECTED PROPERTIES OF THREE ALLIED CHEMICAL COMPANY POLYETHYLENE POLYMERS

Product Designation	Softening Point	Density	Melt Viscosity @ 140°C
AC-1702	85°C	0.88 g/ml	40 cps
AC-617	102°C	0.91 g/ml	180 cps
AC-715	109°C	0.92 g/ml	4000 cps

with nitrogen, and sprayed through several types of nozzles in an effort to obtain a continuous film. The spraying tests were conducted at polymer temperatures of 140°C, 125°C, and 150°C. None of these mixtures formed a thin film (<3 mm) and all films were susceptible to gaps forming between successive spray passes. In addition, thermal contraction raised the edges of the coatings and caused severe cracking in those which formed the better films. None of the final samples was capable of retaining a liquid head, although application rates were between 0.37 amd 0.8 g/cm^2.

Low-Temperature Curing Studies

Those sealing materials which showed acceptable performance in terms of chemical compatibility and permeability were further examined to assess their ability to form a continuous film under adverse conditions. Accidents usually occur during inclement weather when deployment of the sealing material would be difficult; cold and wet soil substrates were considered to be the worst conditions for establishing a sealed surface against hazardous materials.

Test films of Borden Chemical's Polyco 2607 latex, Ashland Chemical's EP 65-68/88 urethane, and Callery Chemical's 115 urethane were prepared on "dry" and "wet" substrates and at selected test temperatures. The Teflon test apparatus and sand substrate were maintained for at least 1 hr at the test temperature and then placed on the conveyor, sprayed, and returned to the test environment to observe the curing process. The substrate temperature and application rate were the controlled variables.

Results with Polyco 2607 --

Data obtained with Polyco 2607 are summarized in Table A-11. The "apparent cure time" was measured as the time required to obtain a non-tacky surface film. Using a 15 to 30 min cure time as the cut-off point for the proposed use, a dry substrate temperature of about 7 to 10°C (45 to 50°F) is the lower limit for this candidate sealing system.

Some of the coatings prepared in this series of tests were used in chemical compatibility tests. These tests, comparing the chemical

compatibility of coatings prepared at these lower temperatures with coatings prepared at room temperature, are included in Table A-5. The results of these exposure tests were similar to those at room temperature. The total liquid transmitted through the coating formed at low temperatures was similar to that measured in previous tests, indicating that the coating, once formed, is similar to that prepared at room temperature.

Results with Ashland's EP 65-86/88 --

The low temperature curing tests for Ashland's EP 65-86/88 are summarized in Table A-12.

A surface film formed on the Ashland urethane when the substrate temperature was as low as -18°C. The curing process was considerably slower at these temperatures, but part of the apparent lag could be attributed to the amount of catalyst used. Previous Ashland samples cured after approximately 1 min. at room temperature while this sample required nearly 2 min. under the same conditions. Ashland assured us that small increases in catalyst concentration would promote low temperature curing without affecting the 6 to 9 month shelf life of this formulation.

Compatibility tests of coatings prepared at these lower temperatures are compared with those prepared at room temperature in Table A-9. The results show no general trends differentiating coatings prepared on cold substrates from those prepared on warmer substrates. Only slight variations were noted in most cases, except that the cold-cured urethane appeared to withstand sulfuric acid, monoethanolamine, and sodium hydroxide somewhat better. This increased resistance may be attributed to the influence of longer curing periods rather than the cure temperature. The time interval between preparation and exposure to challenge liquids was measured in hours for samples prepared at lower temperatures compared to minutes for samples prepared at room temperatures.

Results with Callery's 115 --

Callery Resin 115 was observed to form surface films on the sand substrate at temperatures as low as -20°C (-4°F) (Table A-13). These films required considerably longer times to form than at normal cure temperatures and showed no evidence of foaming. The cure resulted in a pliable film with a smooth glassy surface.

The lower temperatures significantly retard the rate of cure. Water present in the substrate reacts exothermally with the isocyanate to promote further reaction, but does not interfere with the production of an impervious urethane coating. Samples which were kept at -20 to -25°C (-4 to -13°F) foamed as they were allowed to warm to room temperature. This would indicate that the components had not reacted completely and only a surface film was formed.

Compatibility tests of the lower-temperature-cured films are compared with those for foams prepared at room temperature in Table A-8. These

TABLE A-11. LOW TEMPERATURE CURING OF BORDEN CHEMICAL COMPANY "POLYCO 2607"

Condition of Substrate	Temperature Range (°C)	Temperature Range (°F)	Apparent Cure Time (min)
Dry	21 to 23	70 to 74	1 to 15
	17 to 20	62 to 68	1 to 7
	7 to 10	45 to 50	15 to 50
	4 to 5	39 to 42	30 to 50
	0	32	40 to 50
	-15 to -12	5 to 10	15 to 40
	-18	0	>120
Wet	21 to 23	70 to 74	15 to 20
	16 to 18	60 to 65	25 to 40
	7 to 10	45 to 50	40 to 50
	4 to 5	39 to 42	50 to 120
	0 to 4	32 to 39	120 to more than 180

TABLE A-12. LOW TEMPERATURE CURING OF ASHLAND CHEMICAL COMPANY URETHANE FOAM "EP 65-86/88"

Condition of Substrate	Temperature Range (°C)	Temperature Range (°F)	Apparent Cure Time (min)
Dry	0 to 5	32 to 41	15 to 30
	-2 to -5	23 to 28	25 to 60
	-6 to -10	14 to 21	40 to 80
	-10 to -15	5 to 14	55 to 80
	-15 to -20	-4 to 5	70 to 90
Wet	-2 to -5	23 to 28	35 to 40
	-5 to -10	14 to 23	45 to 95
	-6 to -10	14 to 24	70 to 90
	-10 to -15	5 to 14	130 to 150
	-15 to -20	-4 to 5	120 to 140

tests were done after the bottom half of the Teflon apparatus was removed from the refrigerated environment and permitted to equilibrate at room temperature for approximately 1 hr. The dome was placed over the coating and the liquid head established in the burette, exactly as had been done in previous tests.

TABLE A-13. LOW TEMPERATURE CURING OF CALLERY CHEMICAL COMPANY URETHANE "115" FORMULATION

Condition of Substrate	Temperature Range (°C)	(°F)	Apparent Cure Time (min)
Dry	0 to 2	32 to 35	5 to 15
	-6 to -2	21 to 28	7 to 20
	-15 to -10	5 to 10	15 to 20
	-20 to -16	-4 to 4	12 to 20
Wet	0 to 2	32 to 35	20 to 25
	-6 to -2	21 to 28	10 to 25
	-15 to -10	5 to 10	15 to 20
	-20 to -16	-4 to 4	15 to 31

Only acetone and N,N-dimethylformamide resulted in failure of the coating during a 24-hr exposure. In some cases the liquid transmission was slightly less than observed with a coating prepared at room temperature. In others, it was slightly greater. The chemical compatibility of the Callery Chemical Company urethane prepared at low temperatures was not significantly different from that of the normally prepared urethane.

EQUIPMENT

Application Systems

The selection and evaluation of equipment to be used in applying the candidate sealing materials to the spill site was limited to commercial components, just as was done with the sealing materials.

Applicator systems which were considered included: 1) hand-pump pressurized; 2) propellant pressurized; and 3) powered-pump pressurized. These three general types of systems were evaluated for:

1) simplicity;
2) maintenance;
3) logistical support; and
4) economy.

Data from our experimental work indicated that between 80 and 160 lb of material may be required to seal a spill containment area of 1200 ft^2. It was assumed that this area should be covered in 15 to 30 min. The probable range for dispensing rates, using these assumptions, falls in the range of 2.7 to 10.7 lb/min.

One other parameter which does not appear in the experimental data was used in the selection of sealing materials. A maximum liquid viscosity of approximately 2000 cps was considered in the selection of candidate sealing and application systems, since the power requirements for the applicator systems are directly proportional to the viscosity.

Hand-Pumped Systems --

Hand-pumped systems, such as those used for insecticide and paint spraying, may be used to apply these sealing materials. Units are available with capacities between 5.7 and 11.4 liters (1.5 and 3 gal). The largest of these would provide a system weight on the order of 18 kg (40 lb).

Although this type of system is attractive in terms of weight and simplicity, pressure variations and the necessity for continuous or intermittent pumping would be serious limitations.

Propellant-Pressurized Systems --

Propellant-pressurized systems such as fire extinguishers, paint sprays, and other aerosol devices are simple, self-contained units which offer low maintenance requirements and portability; however, detailed design and judicious selection of components are required to achieve all of these attributes in a single applicator system.

Throw-away self-contained, portable propellant-pressurized systems are commercially available for urethanes. Some will dispense as much as 11.5 kg (25 lb) of urethane at rates between 1.25 and 1.4 kg/min (2.75 to 3.1 lb/min). Although they offer a very simple and compact system, the throw-away package is not the favored economic approach.

Most propellant-pressurized systems would be capable of delivering 1.25 to 4.9 kg/min (2.7 to 10.7 lb/min). However, the gas capacities would be insufficient to provide atomizing air, if it was required, and would be limited to that required to propel the coating material from the tank.

An estimate of the cylinder sizes required for supplying atomizing air have been made on the assumption that it would require approximately 28.3 L/min (1 ft^3/min) of gas for each 0.5 kg/min (1 lb/min) of liquid flow (Table A-14). Propellant-pressurized systems far exceed the 18 kg (40 lb) weight target if gas cylinders are employed as the propellant source. They are favored, however, over hand-pumped systems for ease of operation and are more easily maintained than power-pressurized systems.

Power-Pressurized Systems --

Power-pressurized systems may be used where weight and space requirements permit for most spraying or other liquid transfer operations. These systems are of two basic types: electric motor or

combustion engine-powered. Both would require a pump to be included in the system to propel the liquids and/or compress air and, because of the extra weight and added maintenance, are less attractive than the propellant-pressurized system.

The size and power requirements for these systems, based on the amounts of materials to be dispersed, their physical properties, and the desired application rates, have been calculated as a function of flow rates and delivery pressures. The data are presented in Table A-15. The theoretical power requirement is calculated to be approximately 0.4 of the actual requirement because of efficiency losses.

Review and Analysis of Application Systems

Two possibilities were selected as a means of estimating equipment requirements to obtain size, weight, and cost projections for the application of either normal or froth-type urethane foam systems. The two cases considered in depth were: Case I - a completely self-contained system similar to MSA's Rigi-Pak 180 unit; and Case II - a portable unit requiring a power source located a safe distance from the spill site.

Both studies considered application rates of 5 lb/min or more. Case I also considered the need for more uniform spray conditions than experienced with the Rigi-Pak unit, and possibly more uniform component blending. The Case II study was a back-up study to be evaluated further if the Case I system failed to produce favorable sealant application conditions at the desired application and coverage rates, and/or for the total discharge of reagents.

The salient features used in the engineering analyses were:

Case I	Case II
1. An 18 kg (40 lb) self-contained spray package.	1. An 18 kg (40 lb) sealant component package with cleaning solvent for 5 interruptions, and quick-disconnect air pressure manifold and sealant component outlets.
2. An additional regulated gas pressure source (CO_2) to maintain a uniform 150-200 psig pressure.	2. A reuseable hose and powered spray gun assembly.
3. A rapidly replaceable mixing head assembly.	3. A 46 m (150 ft) air hose to a remote compressed air source.
4. The possibility of requirement for a more efficient static in-line mixer unit.	4. An external power source capable of supplying approximately 2.75 KW (2 hp).

TABLE A-14. PRELIMINARY ESTIMATES AND CYLINDER SIZES FOR SUPPLYING ATOMIZING AIR

Sealant to be Dispensed (lb)	Liquid Flow Rate (lb/min)	Gas Flow Rate (cfm)	Cylinder Description
80	2.7	2.7	Size 2 Cylinder
80	5.3	5.3	8 in. x 27 in.
80	10.7	10.7	Tare Wt. 78 lb
160	2.7	2.7	Size 15 Cylinder
160	5.3	5.3	
160	10.7	10.7	

TABLE A-15. CALCULATED POWER REQUIREMENTS AND BATTERY WEIGHTS FOR LIQUID COATING APPLICATOR SYSTEMS

Quantity of Coating (lb)	Delivery Time (min)	Gas Flow Rate (cfm)	1 cfm/lb/min Coating					
			35 psig Supply			40 psig Supply		
			Power		Battery Weight (lb)	Power		Battery Weight (lb)
			Theoretical (hp)	Actual (hp)		Theoretical (hp)	Actual (hp)	
80	15	5.3	0.5	1.23	32	0.54	1.35	35
80	30	2.7	0.24	0.62	16	0.27	0.68	18
160	15	10.7	0.98	2.46	64	1.08	2.7	70
160	30	5.3	0.50	1.23	32	0.59	1.4	36

The operating procedure for the system defined in Case I would be similar to that used for the MSA Rigi-Pak 180 package. Additional operations would include connection to the manifold, connection of the CO_2 cylinder, and pressurization. First estimates of the additional weight and cost have also been made. The proposed system would involve a weight penalty of about 4.5 kg (10 lb) compared with the present Rigi-Pak 180 system. Approximately $50 additional in material costs would be incurred in preparing the proposed system.

Operating procedures for the equipment evaluated in Case II would be similar to those presently used by fire companies. The base system, including power source, would be located at a safe distance but convenient for transporting the urethane containers and spray gun to the spill site. The urethane package would be the same as in Case I, except for a solvent container nestled in the cusp between the component reservoirs.

Weight penalties for this system would result from the drag of the hose and extra weight of a reuseable gun. These are roughly estimated to be several pounds. The major weight penalty for power source and compressor are estimated to be 125 to 136 kg (275 to 300 lb).

The non-recurring equipment cost for the components included in this type of system are estimated to be $1800. The cost penalty to the urethane dispensing system, excluding the power source, is estimated to be in the range of $600 to $1000.

PILOT-SCALE TESTS

Data provided by laboratory tests with the Teflon permeation apparatus were used to develop a test procedure for somewhat larger scale evaluation. Pilot-scale tests of urethane sealing materials were done to obtain data which could be extrapolated to the design of a full-scale test.

Pilot tests were prepared using the following 4 general guidelines:

1) a test area of approximately 1 m^2;
2) flexibility for incorporating various substrates;
3) simulating semi-controlled field conditions; and
4) a portable test apparatus.

The apparatus used for this series of tests was developed in several stages, as difficulties in preparation, sampling, and control of test aparameters were circumvented. The final apparatus, shown schematically in Figure A-4, was used in about 30 tests of candidate sealing materials.

The data obtained in thes tests were analyzed in terms of the variables which would be involved in sealing a "typical" spill substrate. The scope of these investigations was limited by the ability to describe the substrate. Qualitative descriptions of the materials and surface

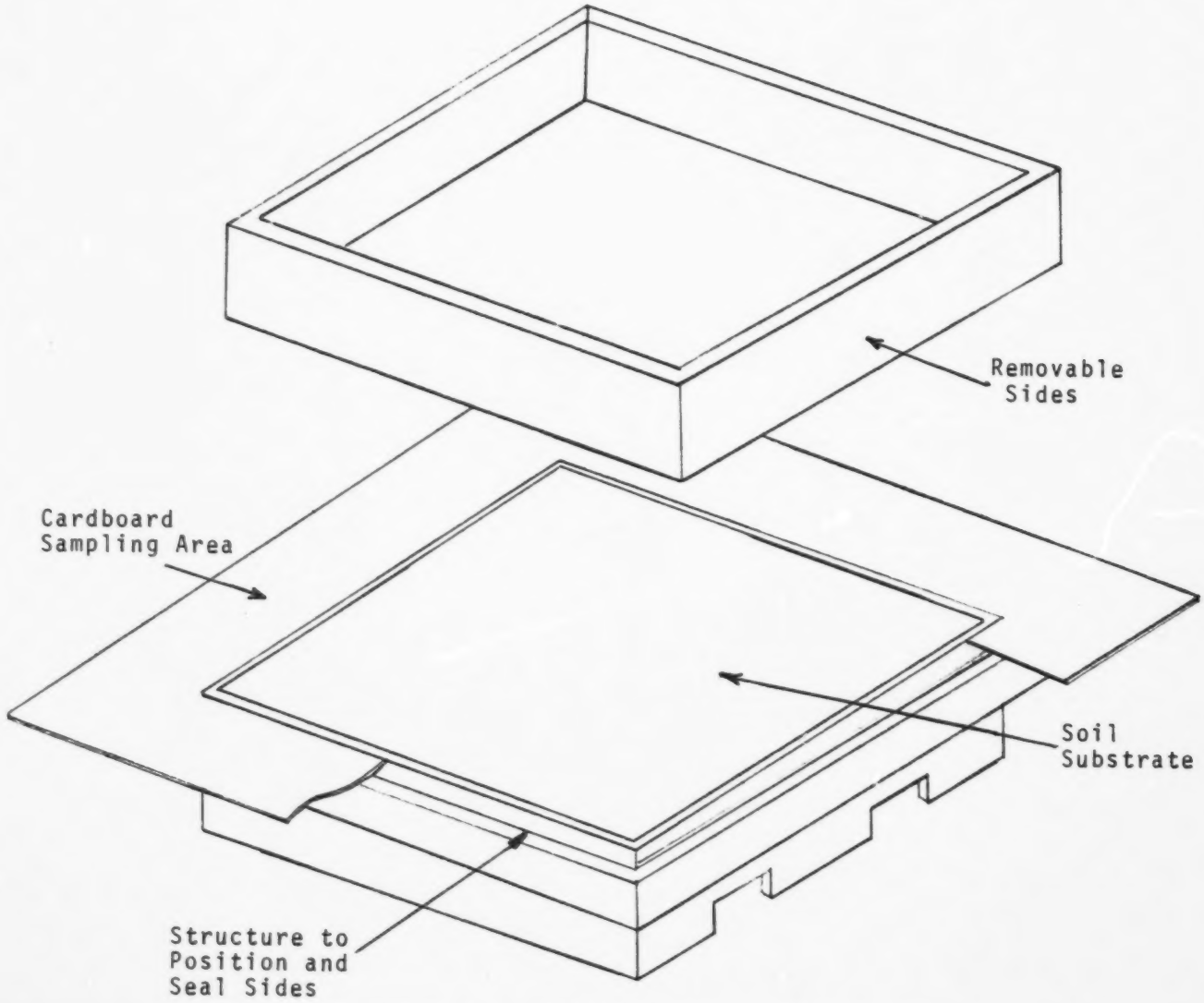

Figure A-4. Modified test apparatus.

irregularities were well-documented in each test.

The pilot-scale tests were designed to use water as the challenge agent. The compatibility and permeability tests indicated that tests with other challenge agents were unnecessary to determine the operating and sealing capabilities of urethane systems. Water was placed over the surface film to a depth of 30.5 cm (1 ft) and monitored throughout the 24-hr tests with a "U"-tube manometer.

The initial tests were made with local soil placed in the apparatus to form a level substrate. After determining that this local soil surface could be sealed, stones and gravel, sand, water, and grass were included in the test substrate to measure their influence on the formation of a continuous seal.

The majority of these tests were made with Callery Chemical Company's basic urethane foam formulation. Several tests also were done with Ashland Chemical Company's urethane to verify the similiarity of urethane formulations.

The Rigi-Pak portable unit, designed primarily for mine use, was used for application of the foams. This system needs no external source of air but mixes the components and a volatile fluorocarbon foam agent with an in-line helical mixer. The basic urethane formulations were applied to the test substrates by spraying through a Binks Model 18 spray gun, a hand-held version of the automatic unit used in the spray chamber. Components were added from two reservoirs by nitrogen pressure, which was regulated to supply the proper ration. Atomizing air was also supplied from the laboratory air line to run the mixer and establish the spray pattern.

The apparatus used in the pilot-scale tests (Figure A-4) was prepared for spraying the candidate sealing systems with a piece of cardboard covering the sealing channel. After the urethane seal was applied, this cardboard was cut free and the sides installed. The final seal to the side boards was made with another frothing urethane formulation, which eliminated any chances for leaks at the edges of the sample. Several sample areas were cut from the cardboard and the application rate was measured by their weight gain.

The results of the pilot-scale tests of urethane sealing systems are collected in Table A-16. Sealing soil substrates with urethane foams required application of approximately 0.1 g/cm^2 (0.2 lb/ft^2). Similar application rates would seal substrates containing small stones and gravel, but not reproducibly. The precision measured for application rates was approximately 0.01 g/cm^2 throughout the coating. The precision in preparing seals which would survive the 24-hr sealing test was less than 50%, however.

The pilot scale tests showed that experience is a key factor in applying coatings under the variety of conditions expected and in understanding the capabilities and limitations of these foamed coatings.

TABLE A-16. RESULTS OF PILOT-SCALE TESTS USING URETHANE SEALANTS

Substrate	Callery Chemical MS Urethane Application Rate (g/cm^2)	Performance	Callery Chemical Rigi-Pak Application Rate (g/cm^2)	Performance	Ashland Chemical EP 65-86/88 Application Rate (g/cm^2)	Performance
Sieved Soil <1 cm (<3/8 in.) dia.	0.05	Failure	0.05	Failure		
	0.12	"	0.1	"		
	0.25	"	0.12	"		
	0.11	"	0.13	Pass		
	0.17	Pass	0.12	"		
	0.1	"				
	0.08	"				
Stones & Gravel	0.13	Failure	0.09	Failure		
	0.49	"	0.16	"		
	0.13	Pass	0.13	"		
	0.17	"	0.14	Pass		
			0.13	"		
Sod (evenly cut)	0.14	Failure	0.16	Failure	0.7	Failure
	0.17	"	0.15	"		
			0.14	Pass		
Growing Grass (uncut)	0.5	Failure	0.16	Failure	0.6	Failure
	0.55	"	.22	"		
			0.52	"		

The bridging effect of the foaming action, which is so necessary to make an effective seal with a minimum of sealant, depends heavily on such variables as sealant and substrate temperatures, the presence of water, the application rate (lb/min), and the manner (single or multiple passes) in which it is applied. Values could be provided for each condition, but only experience will provide the necessary "feel" for people in the field where all these variables may be changing simultaneously.

The results of the pilot-scale tests also indicated that the influences of wind, surface area, and surface defects are difficult to measure, and compensating means are difficult to describe to inexperienced personnel. Whether the unframed film coverage rate will form a continuous coating is a judgement made by the person applying. it. The operator must estimate the influence each of these factors would have and modify the application technique accordingly.

Comparing frothed and normal foaming formulations of commerical urethane systems showed no specific advantages for either type. Urethane foams appeared to have less penetration into normal substrates, while the froths appeared to bridge larger gaps and debris. Neither showed a definite advantage on vegetated substrates. Urethane froths, however, appeared to be somewhat more effective for application on cold or wet substrates.

The course of the program was altered when urethane foam was used in attempts to seal grass-covered substrates. In these tests, coverage rates in excess of 0.6 g/cm^2 (1.3 lb/ft^2) proved incapable of sealing these substrates against water. With a design goal of sealing 1200 ft^2, the coverage rates experienced, even if successful in sealing, precluded its use as an emergency portable system for grassy substrates. This limitation was considered too severe for the anticipated use of the sealant system to continue further development.

The basic problem areas appear to be in the "shadow effect," encountered during spraying, and in the nature of the foaming process. "Shadowing" is common to any spray application and requires exceptional care and conscientious application from all angles to assure complete coverage of the surface. The foaming process for the urethane formulations used in this program helped to minimize the problems of bridging surface discontinuities and "shadowing" in the spray pattern, but applying these systems in the field for accidental spills of hazardous materials would not seal around such obstacles as grass and weeds. Urethane foams which were prepared on grass had fissures which extended through the entire sealant layer.

This undesirable phenomenon is the result of two characteristics of the urethane foaming process:

1) expansion occurs in the direction of least resistance, and
2) reacted surfaces will not grow together.

The exceptionally high probability of encountering vegetated substrates

in conjunction with inclement weather severely restricts the application of the urethane systems. This limitation was considered sufficient to change the priorities of the program and to investigate the use of preformed plastic films to seal unprepared substrates.

APPENDIX B

English to Metric Conversion Factors

English unit	Abbr.	Multiplier	Abbr.	Metric unit
acre	acre	0.405	ha	hectare
acre-foot	acre-ft	1,233.5	cu m	cubic meter
cubic foot	cf	28.32	l	liter
cubic feet per minute	cfm	0.0283	cu m/min	cubic meters per minute
cubic feet per second	cfs	28.32	l/sec	liters per second
cubic inch	cu in.	16.39	cu cm	cubic centimeter
		0.0164	l	liter
cubic yard	cy	0.765	cu m	cubic meter
		764.6	l	liter
degree Fahrenheit	deg F	0.555 (°F-32)	deg C	degree Celsius
feet per minute	fpm	0.00508	m/sec	meters per second
feet per second	fps	0.305	m/sec	meters per second
foot (feet)	ft	0.305	m	meter(s)
gallon(s)	gal.	3.785	l	liter(s)
gallons per acre per day	gad	9.353	l/day/ha	liters per day per hectare
gallons per capita per day	gcd	3.785	l/capita/day	liters per capita per day
gallons per day	gpd	4.381×10^{-5}	l/sec	liters per second
gallons per day per square foot	gpd/sq ft	1.698×10^{-3}	cu m/hr/sq m	cubic meters per hour per square meter
		0.283	cu m/min/ha	cubic meters per minute per hectare
gallons per minute	gpm	0.0631	l/sec	liters per second
gallons per minute per square foot	gpm/sq ft	2.445	cu/m/hr/sq m	cubic meters per hour per square meter
		0.679	l/sec/sq m	liters per second per square meter
gallons per square foot	gpsf	40.743	l/sq m	liters per square meter
horsepower	hp	0.746	kw	kilowatts
inch(es)	in.	2.54	cm	centimeter
inches per hour	in./hr	2.54	cm/hr	centimeters per hour
million gallons	mil gal.	3.785	Ml	megaliters (liters x 10^6)
		3,785.0	cu m	cubic meters
million gallons per acre per day	mgad	0.039	cu m/hr/sq m	cubic meters per hour per square meter
million gallons per day	mgd	43.808	l/sec	liters per second
		0.0438	cu m/sec	cubic meters per second
mile	mi	1.609	km	kilometer
parts per billion	ppb	0.001	mg/l	milligrams per liter
parts per million	ppm	1.0	mg/l	milligrams per liter
pound(s)	lb	0.454	kg	kilogram
		453.6	g	grams
pounds per acre per day	lb/acre/day	0.112	g/day/sq m	grams per day per square meter
pounds per day per acre	lb/day/acre	1.121	kg/day/ha	kilograms per day per hectare
pounds per 1,000 cubic feet	lb/1,000 cf	16.077	g/cu m	grams per cubic meter
pounds per million gallons	lb/mil gal.	0.120	mg/l	milligrams per liter
pounds per cubic foot	pcf	16.02	kg/cu m	kilograms per cubic meter
pounds per square foot	psf	4.882×10^{-4}	kg/sq cm	kilograms per square centimeter
pounds per square inch	psi	0.0703	kg/sq cm	kilograms per square centimeter
square foot	sq ft	0.0929	sq m	square meter
square inch	sq in.	6.452	sq cm	square centimeter
square mile	sq mi	2.590	sq km	square kilometer
square yard	sq yd	0.836	sq m	square meter
standard cubic feet per minute	scfm	1.699	cu m/hr	cubic meters per hour
ton (short)	ton	907.2	kg	kilograms
		0.907	metric ton	metric ton
yard	yd	0.914	m	meter

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